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Waste heat utilization from a direct cycle high temperature gas cooled nuclear reactor for district heating and air conditioning

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WASTE HEAT UTILIZATION FROM A DIRECT CYCLE HIGH TEMPERATURE GAS COOLED NUCLEAR REACTOR FOR DISTRICT HEATING AND AIR CONDITIONING

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ABSTRACT

An analysis was conducted to determine the economic as well as technical feasibility of waste heat utilization from the proposed direct cycle high temperature gas cooled nuclear reactor, as designed by the General Atomic Company.

The rejected heat from this system is at considerably higher temperatures than those normally encountered in conventional steam-electric Rankine cycles. By taking advantage of these higher rejection temperatures, heat was translated into energy available to a district heating and air conditioning service. The transportation of this energy was considered to be in the form of heated and chilled water.

A refrigeration capacity on the order of 100,000 Tons and a heating capability of 5.0×10^9 BTU/hr at a distance of 70 miles was found to be a possibility.

An economic analysis using a discounted cash flow technique, indicated that most of the systems analyzed could be profitable ventures. During the operation of the district heating and air conditioning network, overall utilization of the total reactor heat generation would be in excess of 80.0 per cent.

ACKNOWLEDGEMENT

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I. INTRODUCTION

Direct cycle high temperature gas cooled reactor systems, designed for the generation of electricity, will operate at a cycle efficiency of 37.0 per cent.[11] The remainder of the energy will be rejected as waste heat to the local environment by way of dry air cooling towers.[11] The temperature range of the rejected heat in any one system is between 472°F and 130°F at the precooler stage of the cycle.

The objective of this analysis is to determine an economically and technically feasible method of utilizing the energy rejected from this cycle. The energy is transported to the load center by means of pumped hot and/or cold water, depending on the requirements of the season.

The rejected heat from the reactor cycle provides hot water for the heating system and dry saturated steam for a series of steam jet refrigeration units, that will in turn chill the water for the cooling season.

An investigation into the economic aspects of financing the purchase and construction costs, determination of the operating costs, depreciation allowances, and resultant revenues is of the utmost importance, if the ultimate feasibility of the system is to be determined. A discounted cash flow technique is employed in this aspect of the analysis.

A FORTRAN IV computer program (HOTNCOLD) was developed to assist in the technical and economic analysis of the district heating and cooling networks.

II. METHOD

II.A. Outline of Procedure

The method used in defining and analyzing the district heating and cooling system is as follows:

1. Briefly describe the direct cycle high temperature gas cooled reactor thermal cycle.
2. Analyze the energy source using the following procedure.
   a. determine the heat rejected from the reactor cycle.
   b. determine the heat available to the district heating system at the plant site.
   c. briefly describe the steam jet refrigeration cycle.
   d. determine the quantity of 100 psig steam available to the steam jet refrigeration units.
   e. determine the refrigeration available to the district cooling network at the plant site.
3. Determine the quantity of heat and refrigeration actually delivered to the load center.
   a. conduct a heat transfer analysis to determine the amount of heat and refrigeration that arrives at the load center. Use the computer program HOTNCOLD (routine TECH) to determine this delivery capability.
4. Conduct a discounted cash flow analysis.
   a. determine the installed cost of each operating system.
   b. determine the operating costs of each operating system.

c. determine a cumulative present worth schedule for a thirty year life.

II.B. The Motive Energy Source

As a starting point the energy source of the system must be considered. This source will provide the input energy required to heat and chill the water, that will in turn transport the energy to a district heating and cooling network.

Figure 1.0 is a typical schematic representation of a direct cycle high temperature gas cooled reactor, as designed by General Atomics International.[11] The precooler section is of particular interest here, since it is this area where nearly all the rejected heat of the cycle appears. The temperature of the rejected heat is relatively high when compared to the typical rejection temperatures encountered in conventional steam Rankine cycle. In this system the temperature drop across the precooler ranges from 470°F at the entrance of the precooler to 130°F at the exit; whereas, in the Rankine steam cycle condenser rejection temperatures would be around 105°F. For the case investigated herein a reactor with an electrical power output of 1100 MWe and a cycle efficiency of 37 per cent was chosen as being typical of design considerations at this time.[11]

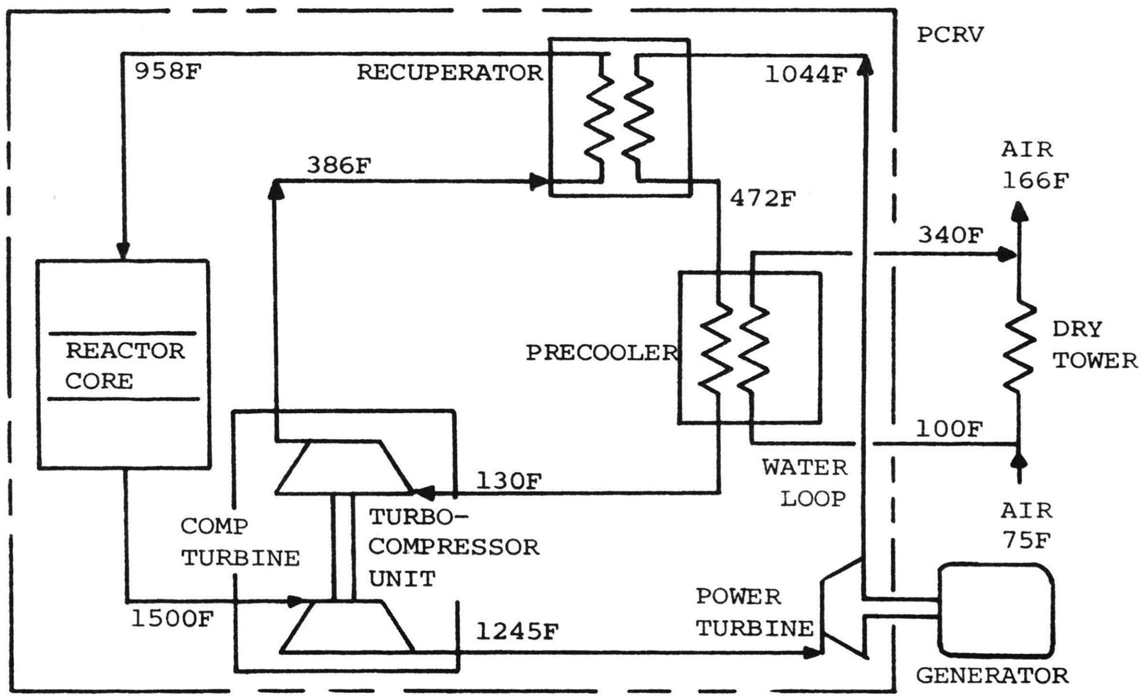

Fig. 1.0. Direct Cycle High Temperature Gas Cooled Reactor.[11]

II.B.1. Thermal balance on the precooler section to determine the steam available to the refrigeration units

Figure 2.0 is a schematic representation of a steam generator acting as the heat rejection point for the precooler stage of the cycle. The steam generator is designed such that helium can transfer heat through a temperature range of 472°F to an exit temperature of 103°F. This heat is transferred to water entering the steam generator at 80°F and exiting as dry saturated steam at 100 psig and a temperature of 338°F. What follows is a thermal balance on the steam generator to determine the mass rate of flow of 100 psig dry saturated steam that is available to the refrigeration units.

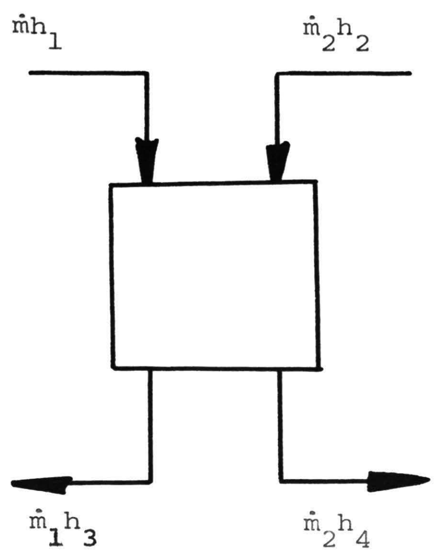

Fig. 2.0. Precooler as Steam Generator.

Where

$\dot{m}_1$ = incoming and exiting mass rate of flow of the helium (lbm/hr)

$\dot{m}_2$ = incoming and exiting mass rate of flow of either the water or steam (lbm/hr)

h_1 = incoming enthalpy of the helium (BTU/lbm)

h_2 = incoming enthalpy of the water (BTU/lbm)

h_3 = exit enthalpy of the helium (BTU/lbm)

h_4 = exit enthalpy of the steam (BTU/lbm)

Performing an energy balance:

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_1 h_3 + \dot{m}_2 h_4 \tag{1}$$

rearranging

$$\dot{m}_1 (h_1 - h_3) = \dot{m}_2 (h_4 - h_3) \tag{2}$$

However, it is known that the left hand term in Equation (2) represents the rejected heat from the cycle. Thus,

$$Q_r = \dot{m}_2 (h_4 - h_3) \tag{3}$$

also

$$Q_{th} = Q_r + Q_e \tag{4}$$

and

$$Q_e = Q_{th} N_{cy} \tag{5}$$

Substituting (5) in (4),

$$Q_r = \frac{Q_e}{N_{cy}} - Q_e \tag{6}$$

where

Q_r = rejected thermal energy (BTU/hr)

Q_{th} = total energy output of the reactor (BTU/hr)

Q_e = total electrical energy generated (BTU/hr)

N_{cy} = cycle efficiency

hence from (6) and (3) we have:

$$\dot{m}_2 = \frac{Q_r}{h_4 - h_3} \tag{7}$$

from (6) Q_r may be determined:

Q_e = 1100 MWe

N_{cy} = .37

$$Q_r = \frac{(1100\text{ MWe})(3.414 \times 10^6)\text{BTU/hr - MWe}}{.37}$$

$$- (1100\text{ MWe})(3.414 \times 10^6\text{ BTU/hr - MWe})$$

$Q_r = 6.394 \times 10^9$ BTU/hr

For the refrigeration system that was selected, 100 psig dry saturated steam is required.[20]

Then at 115 psia saturated:

$$h_4 = 1189.6 \text{ BTU/lbm}$$

The water entering the steam generator is at 70°F then:

$$h_3 = 38.025 \text{ BTU/lbm}$$

solving for the mass rate of flow from (7):

$$\dot{m}_2 = \frac{6.394 \times 10^9 \text{ BTU/hr}}{(1189.6 - 38.025)\text{BTU/lbm}}$$

$$\dot{m}_2 = 5.55 \times 10^6 \text{ lbm/hr} \tag{8}$$

II.C. 40°F Water Available to the System

The energy in the steam calculated in section II.B.1 will act as the motive energy source for a steam jet refrigeration cycle.

II.C.1. Description of the cycle

Water is used as the working fluid in this system. Figure 3.0 is a schematic representation of the refrigeration unit.[20] The evaporator, as in any refrigeration system, is the point at which the actual refrigeration takes place.

Water is evaporated under low pressure thereby cooling the water returning from the load. In order to maintain a sufficiently low pressure in the evaporator, water vapor must be continuously removed from the evaporator. Vapor is removed by entraining evaporator

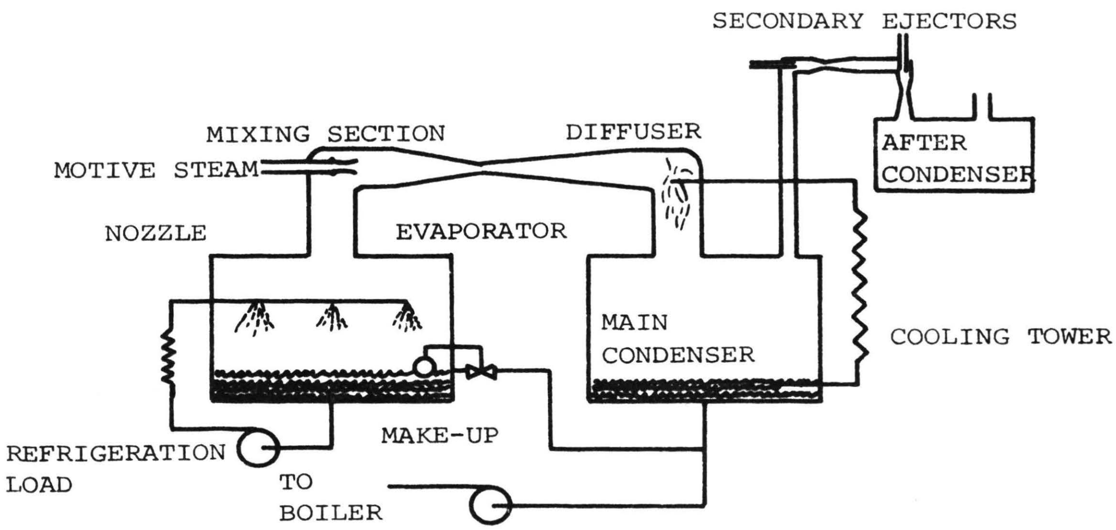

Fig. 3.0. Schematic of the Steam Jet Cycle.

vapor with a supersonic flow of steam from the jet nozzle. Steam leaves the jet nozzle at supersonic velocities and requires a back pressure usually between 20 and 100 psig. The supersonic flow entrains the evaporator vapor at a ratio between 2.0 lbm motive steam per lbm evaporator vapor and 3.0 lbm motive steam per lbm of evaporator vapor. The mixture moves at supersonic velocities through the mixing section at constant pressure to the throat where a shock wave is formed. The mixture compresses through the wave and is returned through the diffuser to the condenser at a higher pressure. Liquid water is pumped from the condenser to the boiler to create motive steam and some is valved to the evaporator as make up water. The cycle is now repeated to maintain a sufficiently low temperature at a continuous rate.

II.C.2. Refrigeration available at the plant site

The amount of refrigeration may now be determined by the use of a parametric graph.[20] Rather than solve the steam jet thermodynamic cycle to determine the refrigeration available, graphs plotting the parameters governing the thermodynamic cycle of the steam jet units are used. Figure 4.0 is a plot of the parameters that govern the operation of the steam jet cycle for standard manufactured units.[20] In this figure the parameters of condenser temperature, condenser water flow rate, booster steam consumption and chilled water temperatures are plotted in their relationships to each other at a constant steam back pressure of 100 psig.

For this case a condenser temperature of 100°F is typical for summer operation and a required chilled water temperature of 40°F is selected. Water in this temperature range is desirable due to the dew point requirements of humidity control. Then from Fig. 4.0

$$\text{at } T_c = 100°F$$
$$T_{cw} = 40°F$$

it is found that

> 1.0 Tons of refrigeration are available for every 27.5 lbm/hr of 100 psig. dry saturated steam moved through the jet nozzle.

where

T_c = condenser temperature

T_{cw} = chilled water temperature

$$RA = \frac{\dot{m}_2}{SRA}$$

where

RA = refrigeration available (Tons)

SRA = specific refrigeration available

thus

$$RA = \frac{5.55 \times 10^6 \text{ lbm/hr}}{27.5 \text{ lbm/hr - Ton}}$$

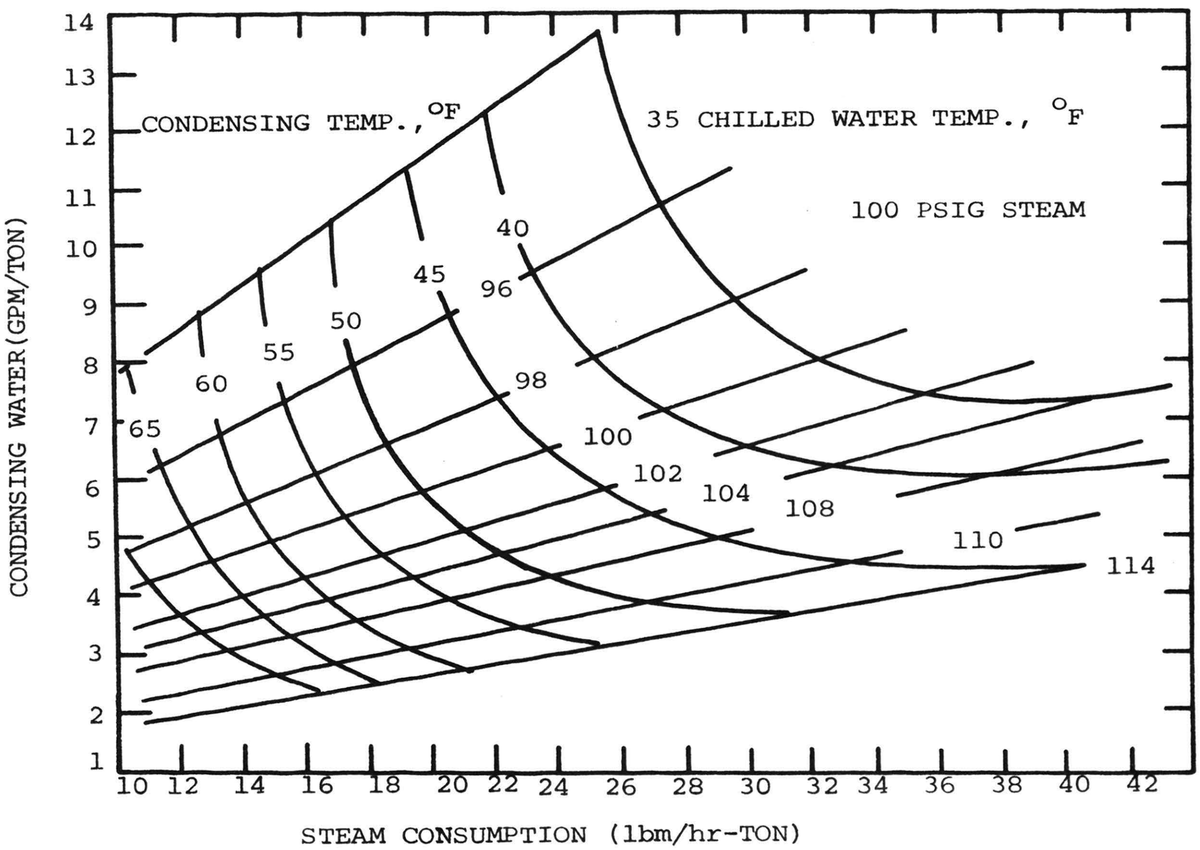

Fig. 4.0 Steam Jet Cycle Parameters

$$RA = 2.05 \times 10^5 \text{ Tons}$$

in terms of BTU/hr this would be

$$RA = (2.02 \times 10^5 \text{ Tons}) \times (12000 \text{ BTU/hr - Ton})$$

$$RA = 2.424 \times 10^9 \text{ BTU/hr}$$

II.C.3. Cooling water available to the pipeline

Consider the thermal balance on the cooling unit given in Fig. 5.0, with water returning from the load, entering the refrigeration unit, being chilled, then returned to the load.

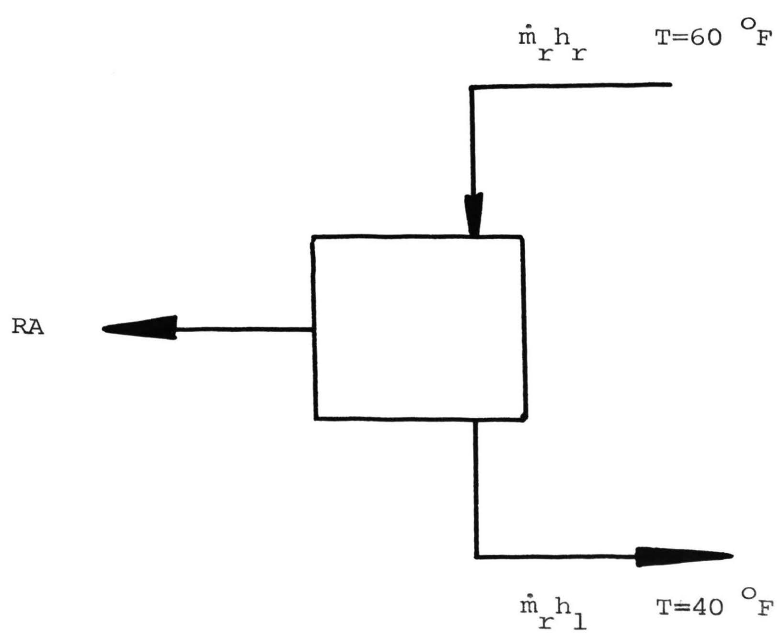

Fig. 5.0. Cooling Unit Thermal Balance.

where

$\dot{m}_r$ = mass rate of flow of chilled water available to the load (lbm/hr)

h_r = enthalpy of the water returning from the load (BTU/lbm)

h_l = enthalpy of water leaving the refrigeration unit

Performing a thermal balance yields:

$$RA = \dot{m}_r h_r - \dot{m}_r h_l$$

$$\dot{m}_l = \frac{RA}{h_r - h_l}$$

$$\dot{m}_l = \frac{2.424 \times 10^9 \text{ BTU/hr}}{(28.06 - 8.027)\text{ BTU/lbm}}$$

$$\dot{m}_l = 1.21 \times 10^8 \text{ lbm/hr}$$

II.D. 200°F Water Available to the System

It must now be determined how much hot water may be delivered from the plant at a temperature of 200°F.

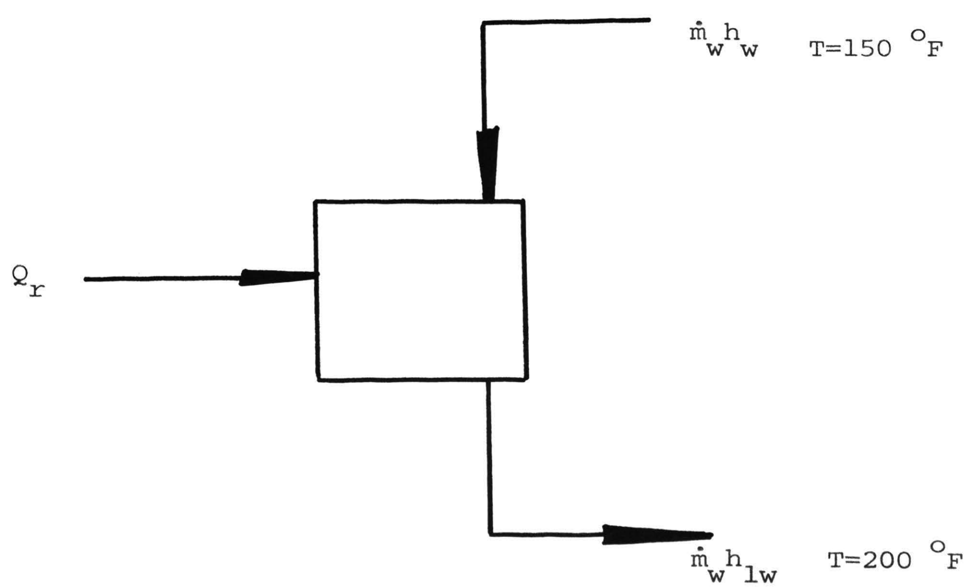

Fig. 6.0. Thermal Balance for Heating System.

where

$\dot{m}_w$ = mass rate of flow of heated water available to the system (lbm/hr)

h_w = enthalpy of the water returning to the plant (BTU/lbm)

h_{lw} = enthalpy of the water leaving the plant and returning to the load (BTU/lbm)

Performing an energy balance:

$$Q_r = \dot{m}_w h_{lw} - \dot{m}_w h_w \tag{12}$$

$$\dot{m}_w = \frac{Q_r}{h_{lw} - h_w} \tag{13}$$

Determining the enthalpies h_w and h_{lw} from the steam tables at the given temperatures and substituting these values in (13) we have:

$$\dot{m}_w = \frac{6.394 \times 10^9 \text{ BTU/hr}}{(168.09 - 117.95)\text{BTU/lbm}}$$

$$\dot{m}_w = .910 \times 10^8 \text{ lbm/hr}$$

It is now known that 0.910×10^8 lbm/hr of 200°F water and 1.210×10^8 lbm/hr of 40°F water is available to the pipeline system.

III. HEAT TRANSFER AND PRESSURE DROP CALCULATIONS

At this point the energy available to the system in the form of heated and chilled water is known. However, since the energy must be transmitted over some distance to the load center, additional factors affecting the actual quantity of energy delivered to the load center must be considered. These factors include; pressure drop calculations as a function of linear water velocity and pipe diameter, and heat transfer through the pipe over the distance to the load.

III.A. Pipeline Pressure Drop Calculations

For a given size pump rated for a fixed horsepower, the proper diameter pipe must be matched to the mass rate of flow at which the pump is rated. This will be done for various diameter pipes by the following procedure.

1. Select the size of the pump.
2. The maximum mass rate of flow has been determined in section II.
3. Determine the linear velocity of the water in the pipe.
4. Determine the pressure drop for a specific diameter linear velocity and friction factor in the pipe.
5. Determine the distance between the pumps in the pipeline.

III.A.1. Pressure drop per mile of pipe

$$DP = \frac{(f)(SV)(5280\ ft/mile)}{D} \frac{G}{10000}^{2} \tag{14}$$

where

DP = pressure drop (psi)/unit length

f = friction factor (Moody determination)

D = pipe diameter (inches)

SV = specific volume (ft^3/lbm)

G = mass rate of flow/pipe cross sectional area (μm/hr-ft^2)

III.A.2. Horsepower required per mile

$$HP = \frac{(A)(H)}{36000} \tag{15}$$

where

HP = horsepower required/mile

H = pressure drop in feet of water/mile

A = mass rate of flow (lbm/sec)

and

$$DBP = \frac{\text{HORSEPOWER OF PUMP SELECTED}}{HP} \tag{16}$$

where

DBP = distance between pumps (miles)

III.B. Pipeline Heat Transfer Calculations

There are two important determinations to be made at this point in the analysis.

1. Determine the heat transfer in or out of the pipeline for a given distance.
2. Determine the energy addition to the water by the pumps.

Consider the schematic in Fig. 7.0 representing a pipeline with a series of pumps.

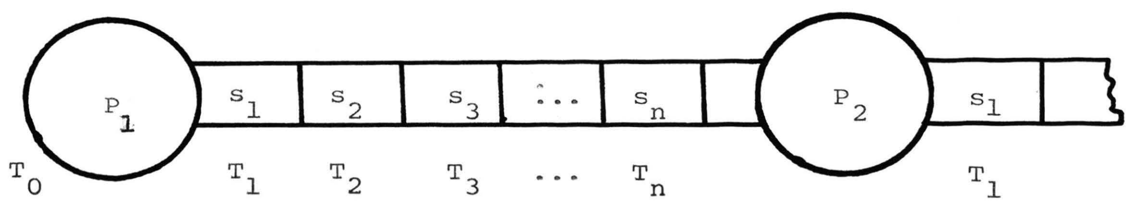

Fig. 7.0. Pipeline Schematic.

Water enters pump P_1 at mass flow rate $\dot{m}$ lbm/hr. The energy added across the pump would be:

$$h'_w = h_w + \frac{HP}{\dot{m}} \tag{17}$$

where

h_w = internal energy of the water before entering pump P_1

HP = power output of the pump (BTU/hr)

h'_w = internal energy of the water after the pump

Immediately following the pump P_1, energy will begin to flow across the wall of the pipe if the ambient temperature is different from that of the water in the pipe (this will be the case in most circumstances). As the water moves downstream from the pump heat will transfer out or into the pipe, as a result of this heat flow the temperature of the water will be a different value from one instant to the next. This fact will in turn effect the rate of heat transfer in or out of the pipe, because the rate of heat transfer is determined by the temperature difference across the pipe. It is possible to approximate the actual case by assuming the temperature of the water to be essentially constant for very small subsections (S_n) of the distance between the pumps (L).

These calculations would be carried out by first determining the rate of heat loss per unit length for a constant temperature difference.

Consider Fig. 8.0 which is a cross sectional representation of an insulated pipe buried in the ground. The steady state heat transfer per unit length is given by:[5]

$$Q_a = \frac{2\pi(T_i - T_G)}{\dfrac{1}{h_1 r_1} + \dfrac{\ln(r_2 - r_1)}{k_p} + \dfrac{\ln(r_3 - r_2)}{K_I} + \dfrac{\ln(r_4 - r_3)}{K_g}} \tag{18}$$

where

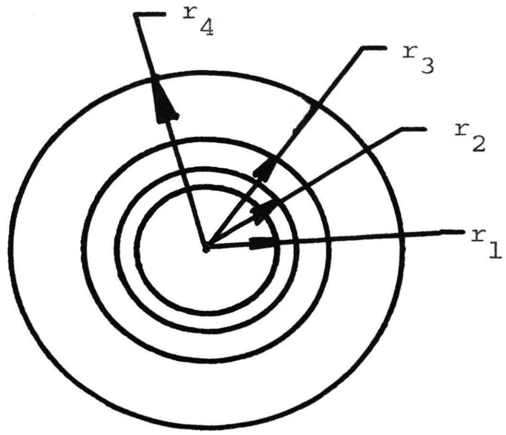

Fig. 8.0. Cross Section of an Insulated Buried Pipe.

$$h_1 = \frac{(NU_d)(k_w)}{2r_1} = \text{the film coefficient} \tag{19}$$

and

NU_d = Nusselt number

$= .023(R_e d)^{.8}(Pr)^B$

$B = .4$ for heating the water

$B = .3$ for cooling the water

Re_d = Reynolds number

$= \dfrac{V\ 2r_1}{v_k}$

P_r = Prandtl number

V = water velocity

v_k = kinematic viscosity of the water

k_w = thermal conductivity of the water

T_i = temperature of the water

T_G = temperature of the ground the pipe is buried in

r_1 = inner radius of the pipe

r_3 = outer radius of the insulation

r_4 = outer radius of the soil around the pipe

k_p = thermal conductivity of the pipe (BTU/hr-ft-°F)

k_I = thermal conductivity of the insulation

k_g = thermal conductivity of the ground

Q_a = heat transfer per unit length (BTU/hr-ft)

The sequence of events used in determining the heat transfer in each section would be:

For heat transfer in section s_1 Fig. 7.0:

1. Determine the pump energy addition to the water by using equation (17) and find h'_w.
2. From the steam tables determine the temperature T_2 (Fig. 7.0) from the value h'_w.
3. Given the ground temperature T_G (Fig. 8.0) and having calculated the water temperature $T_1 = T_i$ use equation (18) to determine the heat transferred per unit length.
4. Determine the film coefficient h_1 by equation (19).
5. Determine the heat transferred through section s_1 of the pipe Q_a.
6. Determine the new enthalpy of the water by:

$$h''_w = h'_w + \frac{Q_a}{\dot{m}}$$

7. Knowing h" determine the corresponding temperature $T_2 = T_i$ from the thermodynamic tables and use this as the constant temperature for section s_2.

8. Repeat steps 1 through 7 for all sections through s_n until the next pump or the load center is reached.

III.C. Energy Available at the Load Center

In section III.A and III.B, the technique for determining the temperature at any point in the pipeline was discussed. Now the actual amount of energy available at the load center may be determined.

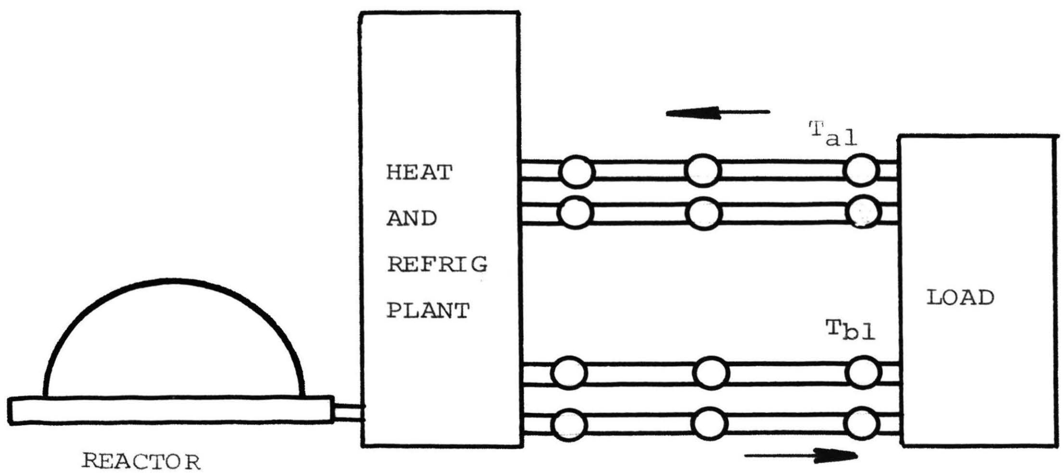

Fig. 9.0. Schematic of Pipeline Delivery System.

The three important factors involved in this analysis are:

1. Determination of the temperature before the load
2. Determination of the temperature after the load
3. Determination of the mass rate of flow

The temperature before the load was calculated by the technique outlined in the previous sections and $\dot{m}$ is known. The temperature after the load, is in most instances variable, dependent on the weather conditions effecting the local requirements. For purposes of this analysis a maximum temperature differential across the load is specified.

The temperature increase across the load for the air conditioning service never exceeds 12°F. Temperature increases greater than 12°F would make humidity control difficult. The temperature change across the load for heating was chosen to be 35°F. Temperature drops greater than 35°F are possible; however, the lower the temperature entering the load center the greater the heat exchanger surfaces required to deliver an equivalent amount of energy. Since the temperature change across the load will be a function of the temperature of the water entering the load center; the temperature change across the load must also be a function of the distance from the load center.

Assumptions

T_{al} = 55°F for the air conditioning service

T_{al} = 150°F for the heating service

where

T_{al} = temperature after the load

The energy left at the load would be:

$$Q_l = \dot{m}h_{bl} - \dot{m}h_{al}$$

where

Q_l = energy removed from, or added to the load center (BTU/hr)

h_{bl} = enthalpy of the water before the load (BTU/lbm)

h_{al} = enthalpy of the water after the load (BTU/lbm)

III.D. Demonstration of Method

A computer program HOTNCOLD (subroutine TECH) was developed to utilize the type of analysis outlined in the above sections. The following input to the program was used for the systems analyzed in this investigation.

III.D.1. Program input

Temperature drop across the load = 20°F to 35°F (heating)

Temperature rise across the load = less than 12°F (cooling)

Number of pipes = 2 in each direction**

Water mass rate of flow = variable $.8 \times 10^8$ lbm/hr to $.3 \times 10^8$ lbm/hr

Pump size = 7000 horsepower

Thermal conductivity of the water = .338 BTU/hr-ft°F

Thermal conductivity of the pipe = 25.0 BTU/hr-ft°F

** two pipes were selected because there is sufficient water available to the system at full load to accommodate a two pipe system

Thermal conductivity of the insulation	= .13 BTU/hr-ft°F
Thermal conductivity of the soil	= 1.0 BTU/hr-ft°F
Friction factor (Moody determination)	= .015
Maximum distance to the load centre	= 110 miles
Pipe diameter	= 30 to 60 inches
Kinematic viscosity of the water	= function of temperature in tabular form
Prandtl Number	= function of temperature in tabular form
Months of heating service	= 4 months (full load)
Months of cooling service	= 3 months (full load)

III.E. Results

The following figures are the results of the calculations done in subroutine TECH in the program HOTNCOLD.

The graphs illustrate the refrigeration or heat available at a given distance PER PIPE. For example it is seen from Fig. 16.0 that 51820.0 tons of refrigeration is available per delivery pipe at a distance of 100.0 miles with a 60 inch pipe and a mass rate of flow of 56.0 x 10^6 lbm/hr of chilled water.

At the same distance from Fig. 10.0, 1.91 x 10^9 BTU/hr is available to a heating load with the same mass rate of flow of water. It is known from sections II.C.2 and II.B that 1.21 x 10^8 lbm of chilled water and .910 x 10^8 lbm/hr of heated water are actually available to the pipeline. Obviously what this means is that two pipes may be used to deliver at maximum load. When the season does not require a strictly heating or air conditioning service, hot water may be shipped in one pipe and cold in the other.

The following symbols key the mass rates of flow on Figures 10.0 through 17.0.

$$m1 = 57 \times 10^6 \text{ lbm/hr}$$

$$m2 = 56 \times 10^6 \text{ lbm/hr}$$

$$m3 = 55 \times 10^6 \text{ lbm/hr}$$

$$m4 = 54 \times 10^6 \text{ lbm/hr}$$

$$m5 = 53 \times 10^6 \text{ lbm/hr}$$

$$m6 = 52 \times 10^6 \text{ lbm/hr}$$

$$m7 = 51 \times 10^6 \text{ lbm/hr}$$

$$m8 = 50 \times 10^6 \text{ lbm/hr}$$

$$m9 = 49 \times 10^6 \text{ lbm/hr}$$

$$m10 = 48 \times 10^6 \text{ lbm/hr}$$

$$m11 = 47 \times 10^6 \text{ lbm/hr}$$

$$m12 = 46 \times 10^6 \text{ lbm/hr}$$

$$m13 = 45 \times 10^6 \text{ lbm/hr}$$

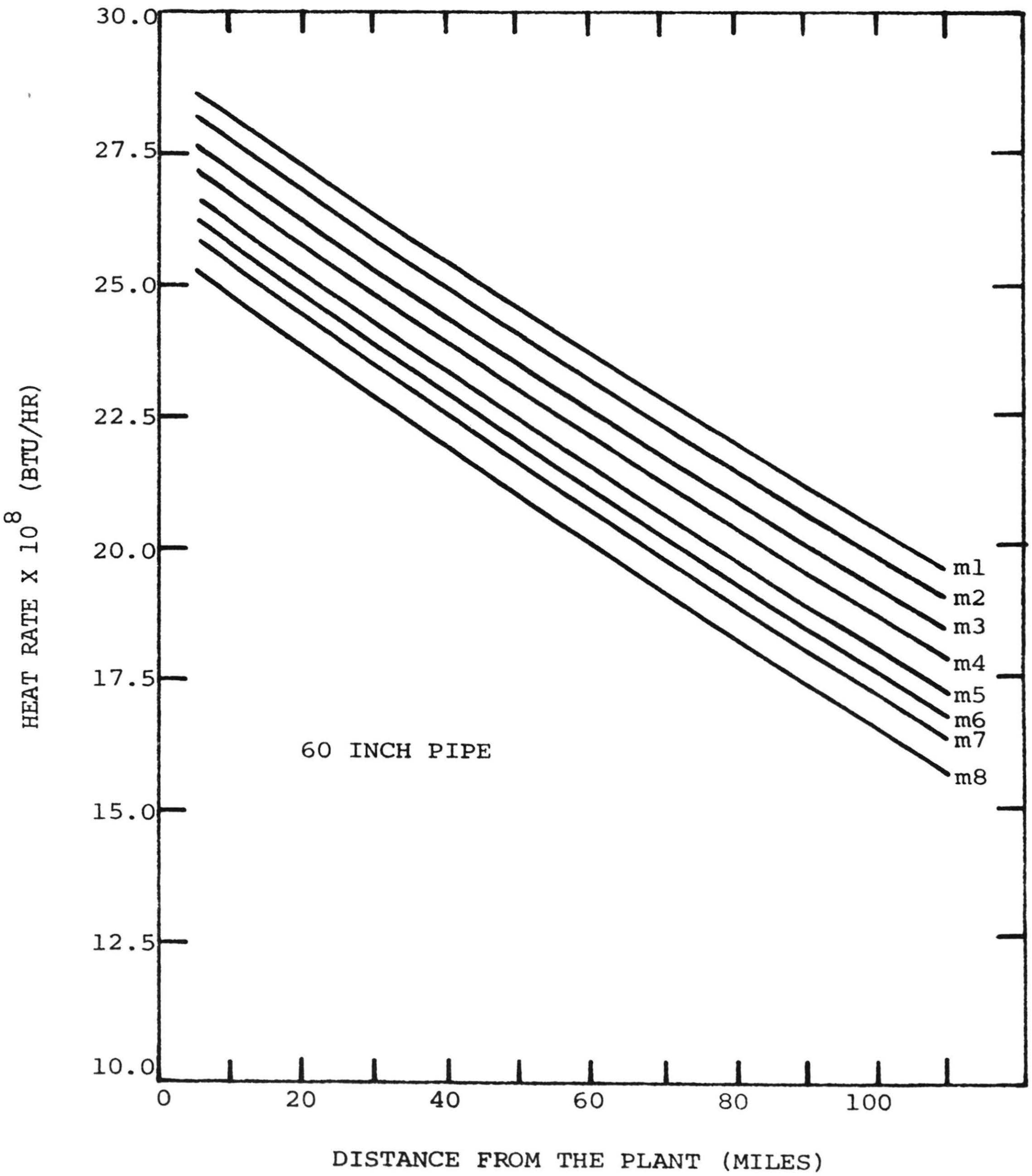

Fig. 10.0. Heat Rate vs. Distance. m1-m8

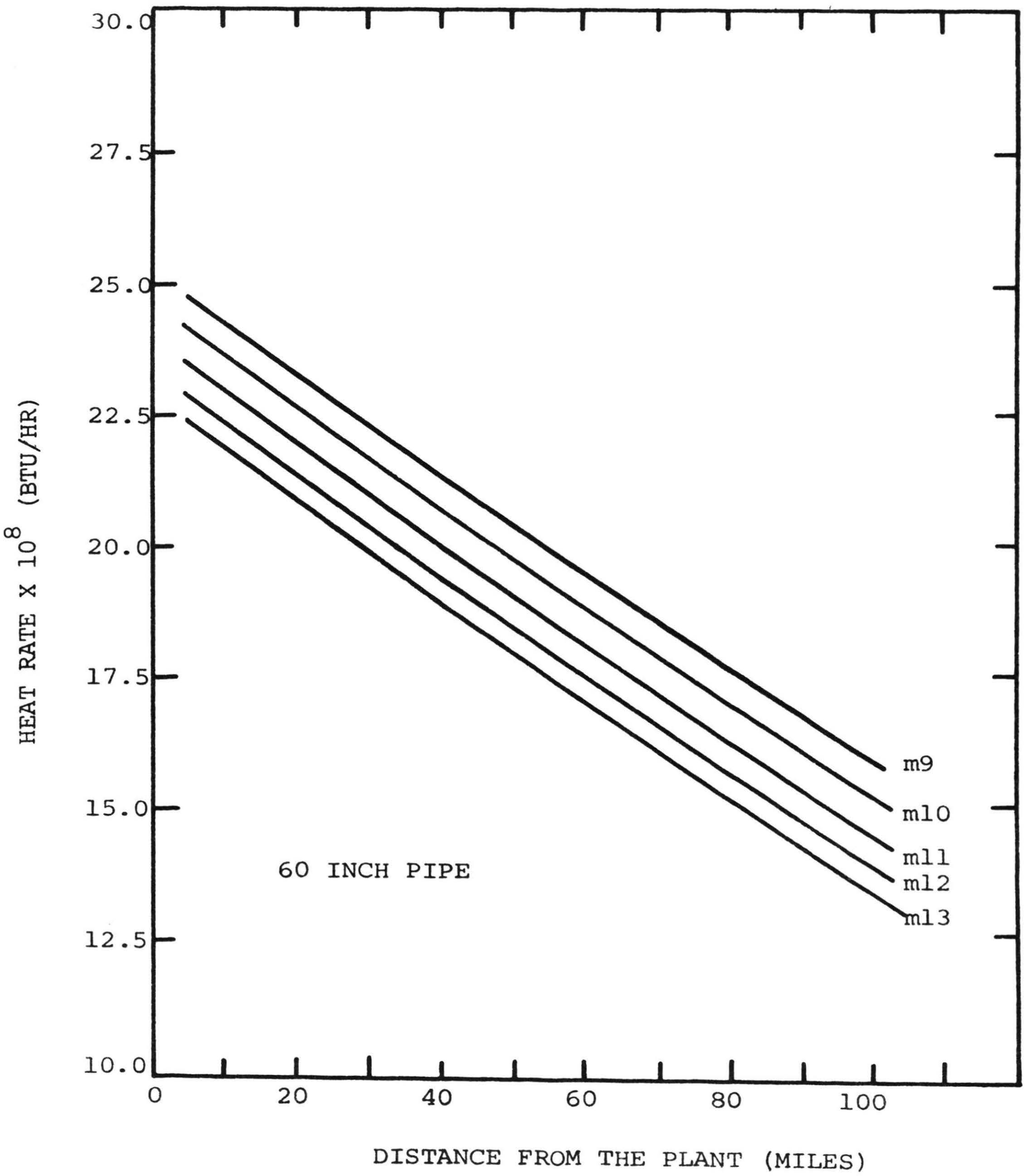

Fig. 11.0. Heat Rate vs. Distance. m9-m13

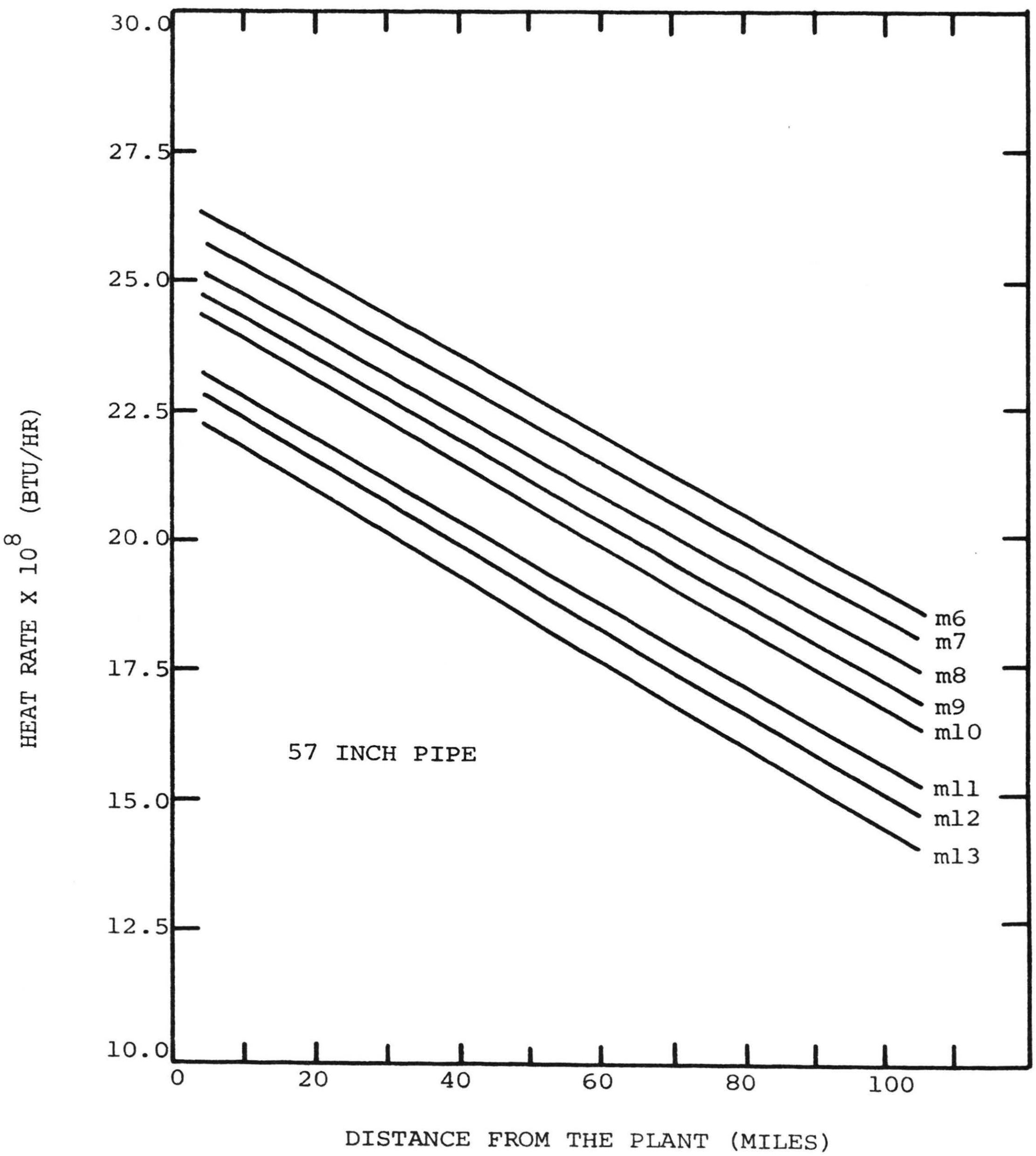

Fig. 12.0. Heat Rate vs. Distance. m6-m13

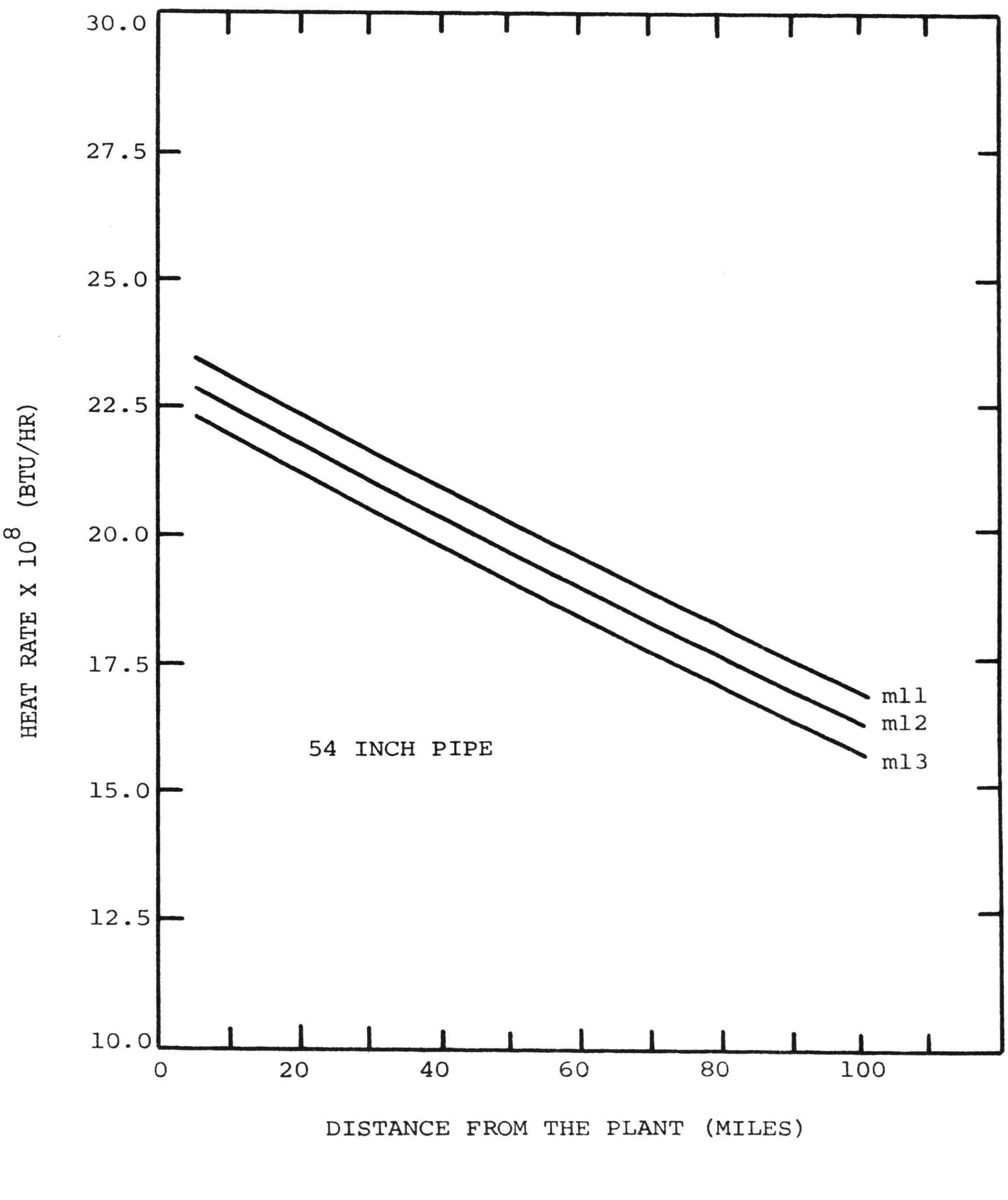

Fig. 13.0. Heat Rate vs. Distance. ml1-ml3

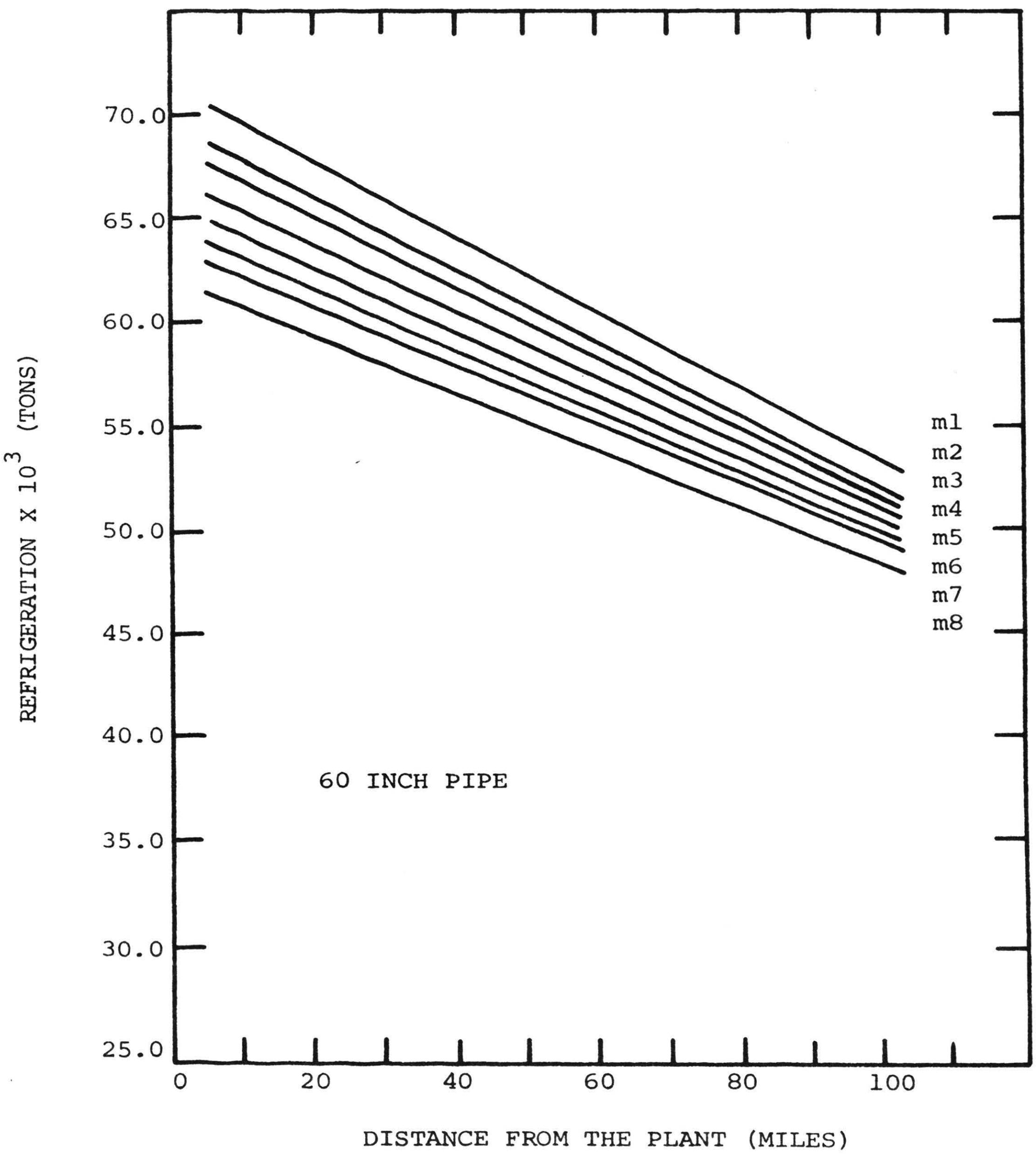

Fig. 14.0. Refrigeration vs. Distance from the Plant. m1-m8

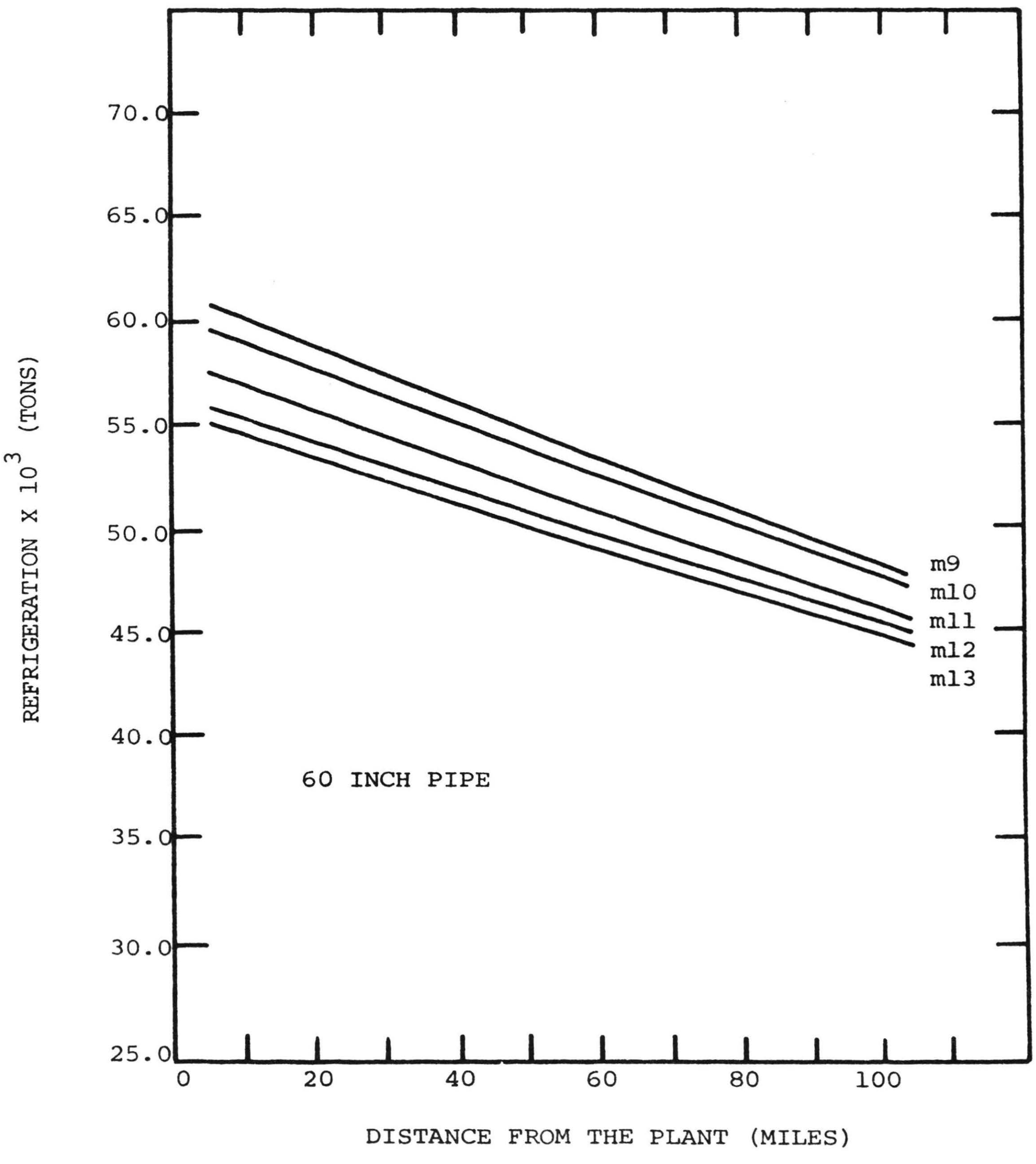

Fig. 15.0. Refrigeration vs. Distance from the Plant. m9-m13

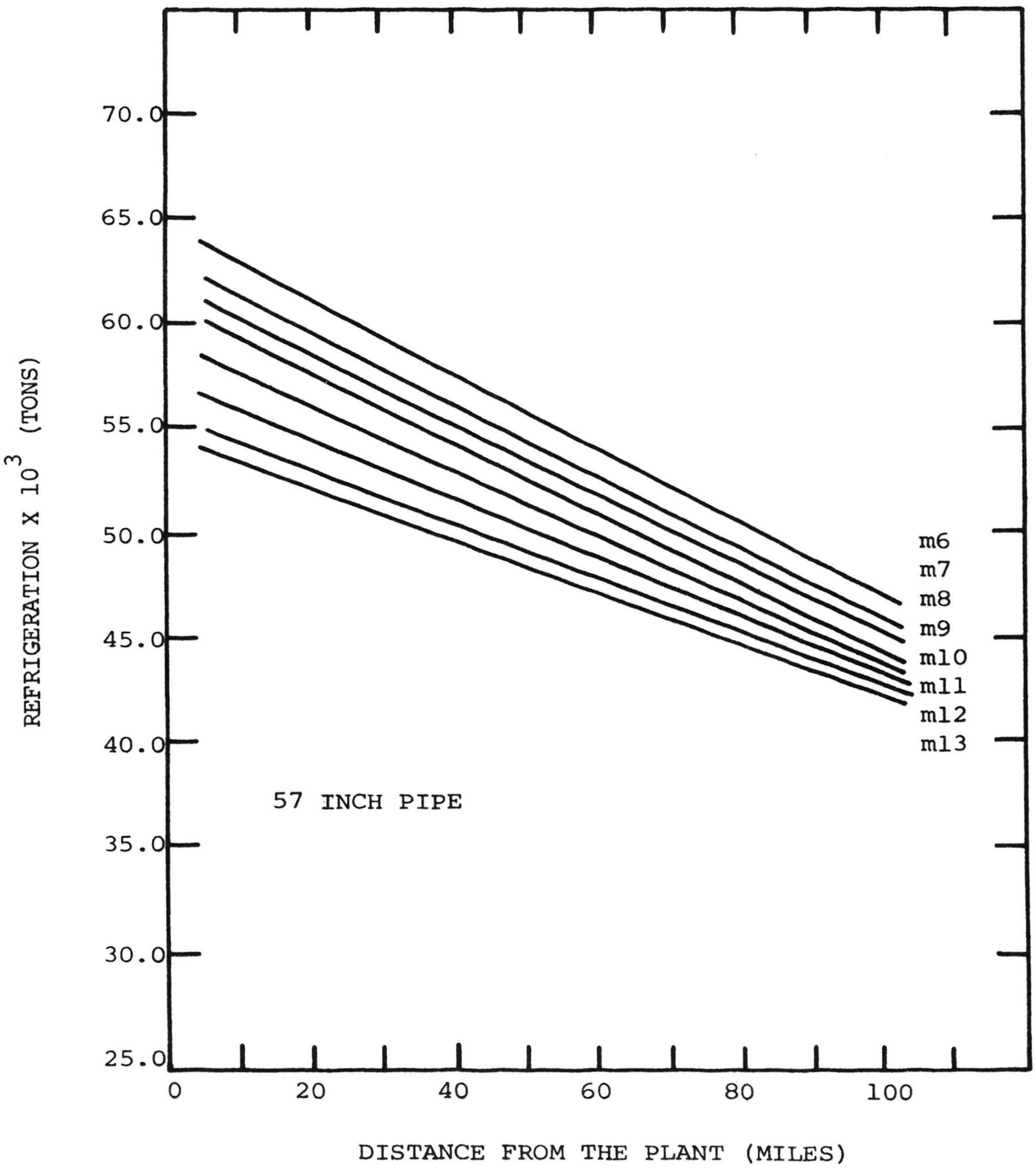

Fig. 16.0. Refrigeration vs. Distance from the Plant. m6-m13

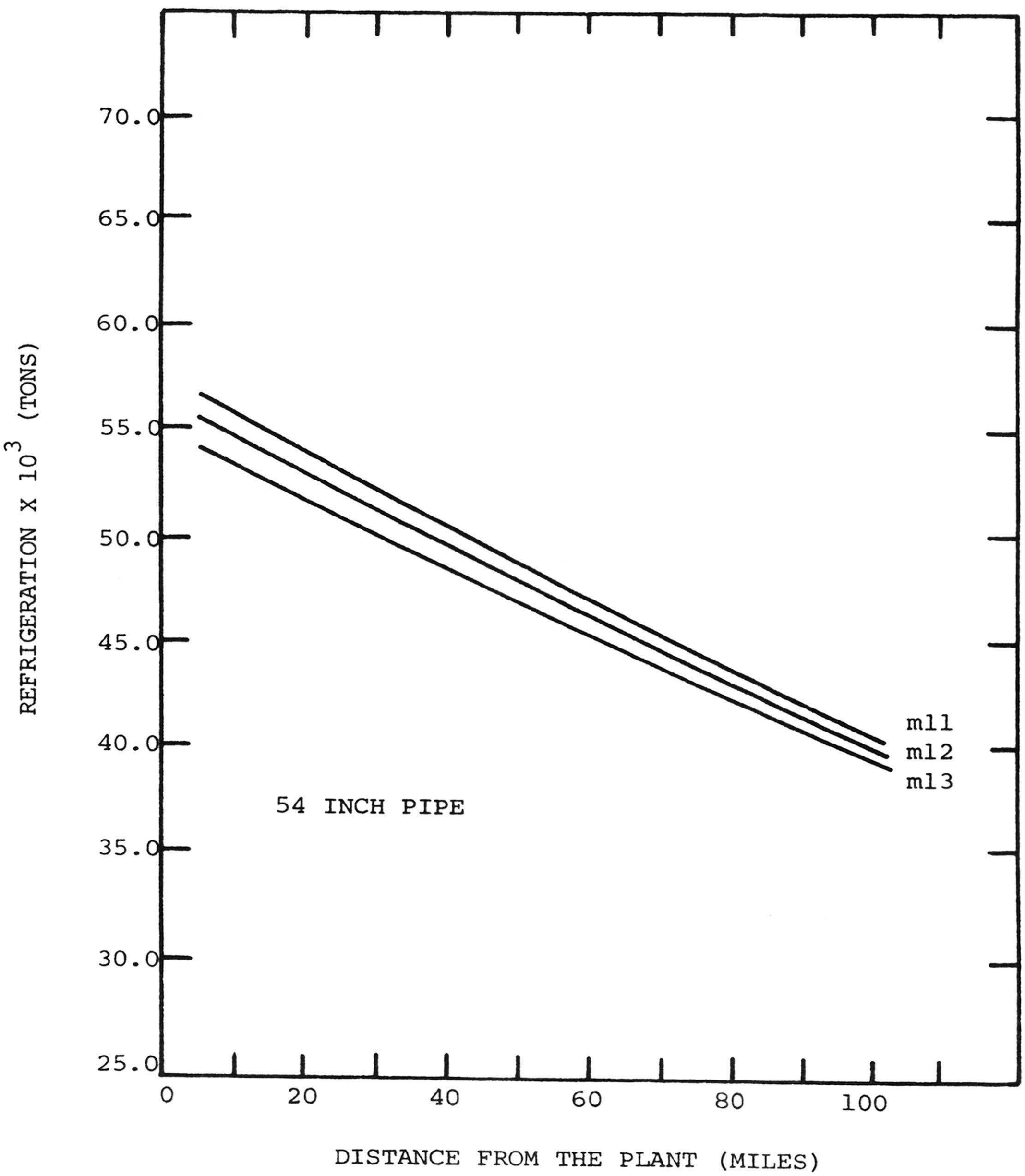

Fig. 17.0. Refrigeration vs. Distance from the Plant. m11-m13

IV. CASH FLOW ANALYSIS

A discounted cash flow analysis is conducted to yield an initial look at the economic desirability of undertaking the district heating and cooling project.

IV.A. Procedure

The following procedure was used to carry out the cash flow analysis:

1. These parameters are held at fixed levels:
   a. The revenue rate for energy sold
   b. The discounting rate
   c. The cost and revenue escalation rate
   d. Depreciation scheme for capital investments
2. Decide which parameters to vary as a function of the physical system:
   a. The installed cost of the piping system
   b. The maintenance cost of the system
   c. Installed cost of the refrigeration system
   d. Operating cost of the system
   e. Tax costs
3. For each unique set of parameters carry out the following:
   a. Establish a 30 year face value cash flow table with escalation (inflation) costs included
   b. Discount the face value table to a single present worth cash in and cash out value

c. Calculate the cumulative present worth table for the 30 year life of the project.

IV.A.1. Rates

Discounting interest rate	= 10%
Cost and revenue escalation (inflation)	= 4.5%
Tax rate (income)	= 50.0%
Bond rate of interest	= 7.0%
Preferred stock interest	= 7.0%
Common stock interest	= 14.0%
Cost of heat	= $1.00/million BTU
Cost of refrigeration	= $2.00/million BTU
Life	= 30 years
Property tax rate	= 2.0%
Installed cost of pumping stations	= $275.00/horsepower
Installed costs of controls and communications	= $1,000,000
Pump operating costs	= $.01/KWh
Maintenance	= 2.0% of installed cost
Installed cost of piping	= Fig. 19.0

IV.A.2. Example cash flow

The following is an excerpt from Appendix D where a detailed development of this example is given. The following example situation was developed for cash flows in the years they occur for an initial investment of $1000.00, maintenance expense of $1000.00/year and \$2000.00/year revenue.

Table 1.0. \$1000 Investment Cash Flow Table.

YEAR	CI	MAINT & OP	TAX	PRTX	FC	REV	EF
1	1000.0	1045.0	402.0	20.0	91.0	2090.0	1.045
2		1092.0	445.4	20.0	91.0	2184.0	1.092
3		1141.0	485.7	20.0	91.0	2282.2	1.141
4		1192.5	524.5	20.0	91.0	2385.0	1.192
5		1246.2	561.6	20.0	91.0	2492.4	1.246
6		1302.3	597.9	20.0	91.0	2604.5	1.302
7		1360.9	627.2	20.0	91.0	2721.7	1.360
8		1422.2	657.8	20.0	91.0	2844.2	1.422
9		1486.1	689.8	20.0	91.0	2972.2	1.486
10		1552.9	723.2	20.0	91.0	3105.9	1.552

where

CI = capital investment

FC = finance charges + dividends

= (.40 x CI x BROI)+(.30 x CI x CROI)+(.30 x PROI)

BROI = bond rate of interest

CROI = common rate of interest

PROI = preferred rate of interest

per cent bonds = 40%

per cent preferred = 30%

per cent common = 30%

PRTX = property taxes

= 2.0% x CI

TAXES = income taxes

IV.A.3. Depreciation scheme

The following method was used to calculate a dual declining balance depreciation scheme.

Year	Undepreciated balance	Depreciation
1	CI(1)	CI x 2.0 x SLR = dep(1)
2	CI(2) = CI(1) - dep(1)	CI(2) x 2.0 x SLR = dep(2)
3	CI(3) = CI(2) - dep(2)	CI(3) x 2.0 x SLR = dep(3)
.		
.		
.		
N	CI(N) = CI(N-1) - dep(N-1)	CI(N) x 2.0 x SLR = dep(N)

where

SLR = straight line depreciation rate

$$= \frac{1}{\text{Project life (years)}} \tag{21}$$

In this scheme we switch to a straight line depreciation scheme when the undepreciated balance divided by the number of years remaining in the life of the project is greater than the dual declining balance depreciation value.

IV.A.4. Income tax calculations

Knowing the depreciation schedule, the income tax calculations may now be carried out. A tax rate of 50% of net income is used.

$$\text{Taxes}(N) = [(R(N) - (OP(N) + MAINT(N) + DEP(N) + PT(N) + \text{Bond interest}(N))] \times .50 \quad (22)$$

where

N = any one year in the project life from 1 through 30 inclusive

$R(N)$ = revenue in any one year

$= R(1 + k)^N$

$FC(N)$ = finance charges for any one year

$OP(N)$ = operating expenses in any one year

$= OP(1 + k)^N$

$MAINT(N)$ = maintenance expenses in any one year

$= MAINT(1 + k)^N$

$DEP(N)$ = depreciation expense (outlined in section IV.A.3)

$PT(N)$ = property tax in any one year

Bond Interest = interest paid on the bonds only to finance part of the project

IV.A.5. Net cash flow

The face value net cash flow may now be determined.

$$NCF(N) = [R(N) - (OP(N) + MAINT(N) + \text{INCOME TAXES}(N) + PT(N) + FC(N) + CR)] \quad (23)$$

where

$NCF(N)$ = net cash flow for any one year

CR = capital recovery

and

$$PW_o(N) = \frac{NCF(N)}{(1 + i)^N} \tag{24}$$

where

$PW_o(N)$ = the present worth at time zero for any one year (N).

thus

$$PVI = PW_o(1) + PW_o(2) + PW_o(3) + \cdots PW_o(30) \tag{25}$$

where

PVI = cumulative present value of income at i% for a project life of 30 years.

This type of cash flow analysis was conducted for the systems represented in figures 20 through 25. The computer program HOTNCOLD subroutine CASH was developed using the technique outlined in the above sections to process the cash flow calculations and prepare the plots therefrom.

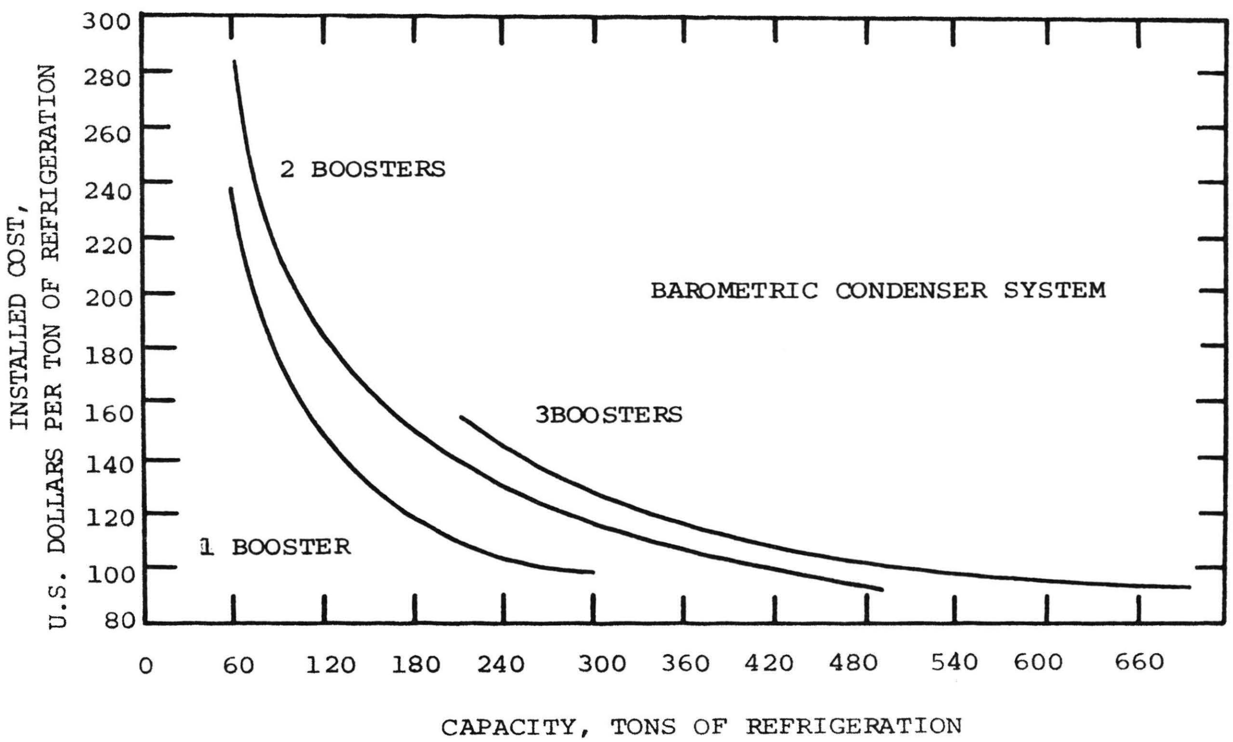

Fig. 18.0 Installed Cost of Refrigeration Systems vs. Refrigeration Capacity.

The following figure (Fig. 19.0) was developed from cost projections from pipeline data given for the years 1951 through 1967. These data were projected to the year 1974 to give the curve represented in Fig. 19.0. These data were published by the Federal Power Commission in the March 1969 issue of Pipeline Engineer. With the shortage of fabricated steel pipe there is no accurate way of determining the actual price of the pipe in March 1974. Although the graph does most probably represent the range in which the pipe costs would fall if pipe were available.

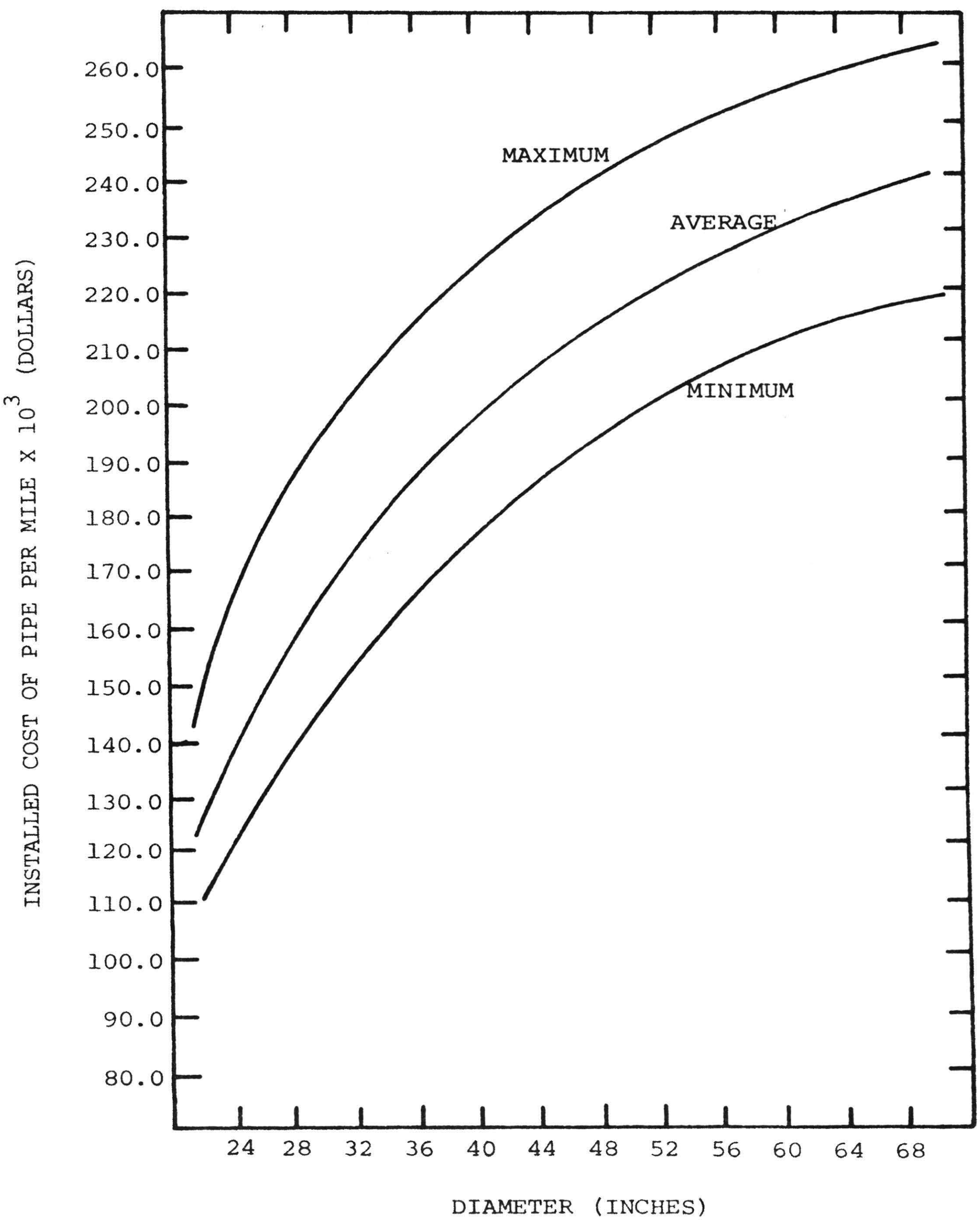

Fig. 19.0. Installed Cost of Pipe vs. Diameter.

IV.B. Results of the Cash Flow Analysis

The following figures are the results of the calculations done in subroutine CASH in the program HOTNCOLD. The graphs illustrate the present value net cumulative cash flow for a two pipe (two in each direction) hot water and cold water delivery system. For example, it is seen from figure 20.0 that the 10% cumulative present worth of the net cash flow for a 50 mile installation at a mass rate of flow of 56×10^6 lbm/hr (m2) is $52,000,000. At the distance where the line crosses the 0.0 point the system would have an internal rate of return of 10.0%. Above the dashed line represents money earned above 10.0%, below the dashed line represents money short of 10.0% internal rate of return.

The following symbols key the mass rates of flow on figures 20 through 25.

$m1 = 57 \times 10^6$ lbm/hr

$m2 = 56 \times 10^6$ lbm/hr

$m3 = 55 \times 10^6$ lbm/hr

$m4 = 54 \times 10^6$ lbm/hr

$m5 = 53 \times 10^6$ lbm/hr

$m6 = 52 \times 10^6$ lbm/hr

$m7 = 51 \times 10^6$ lbm/hr

$m8 = 50 \times 10^6$ lbm/hr

$m9 = 48 \times 10^6$ lbm/hr

$m10 = 48 \times 10^6$ lbm/hr

$$m11 = 47 \times 10^6 \text{ lbm/hr}$$

$$m12 = 46 \times 10^6 \text{ lbm/hr}$$

$$m13 = 45 \times 10^6 \text{ lbm/hr}$$

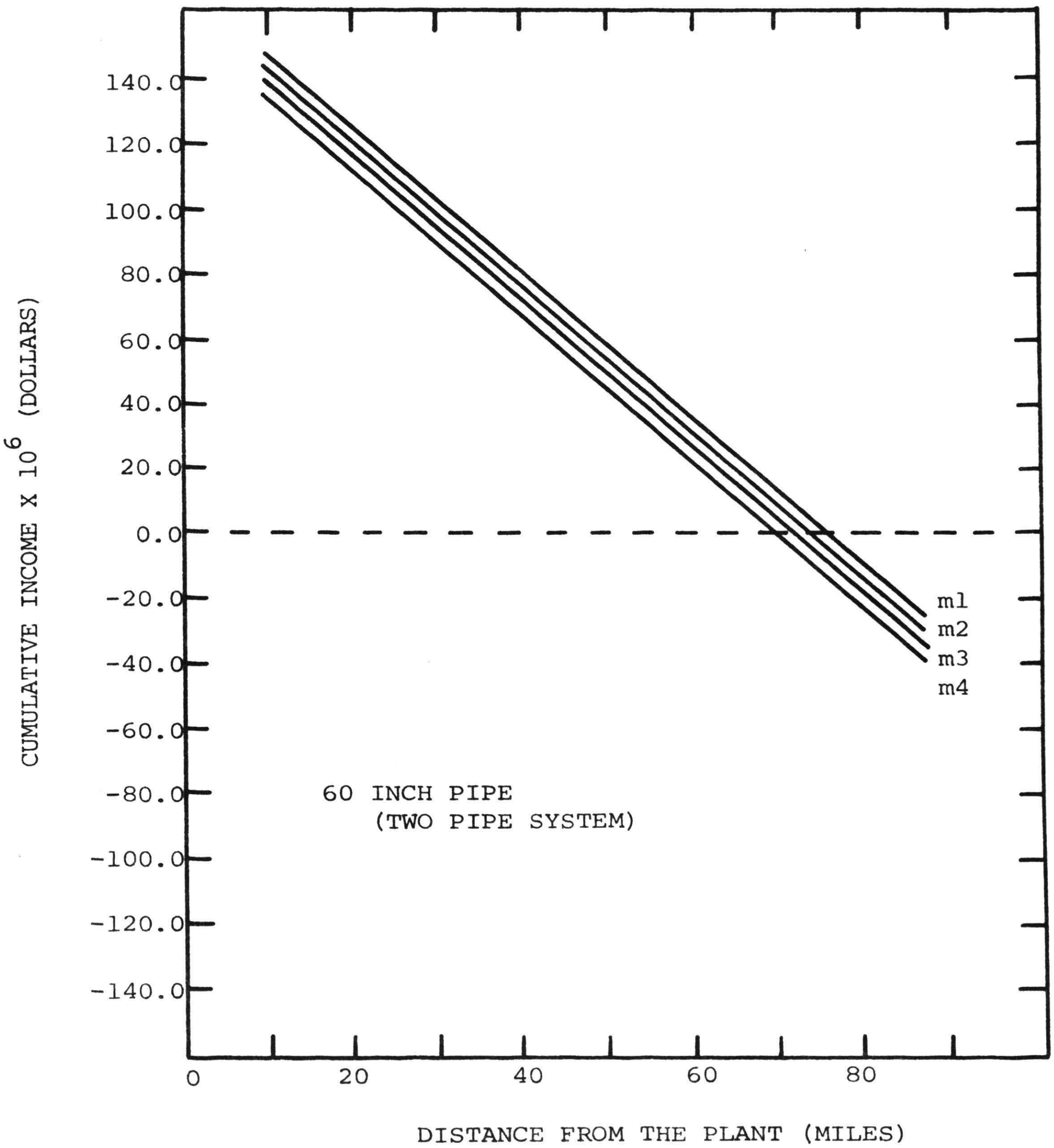

Fig. 20.0. Present Value of Cumulative Income at 10% for a 30 Year Life vs. Years. m1-m4

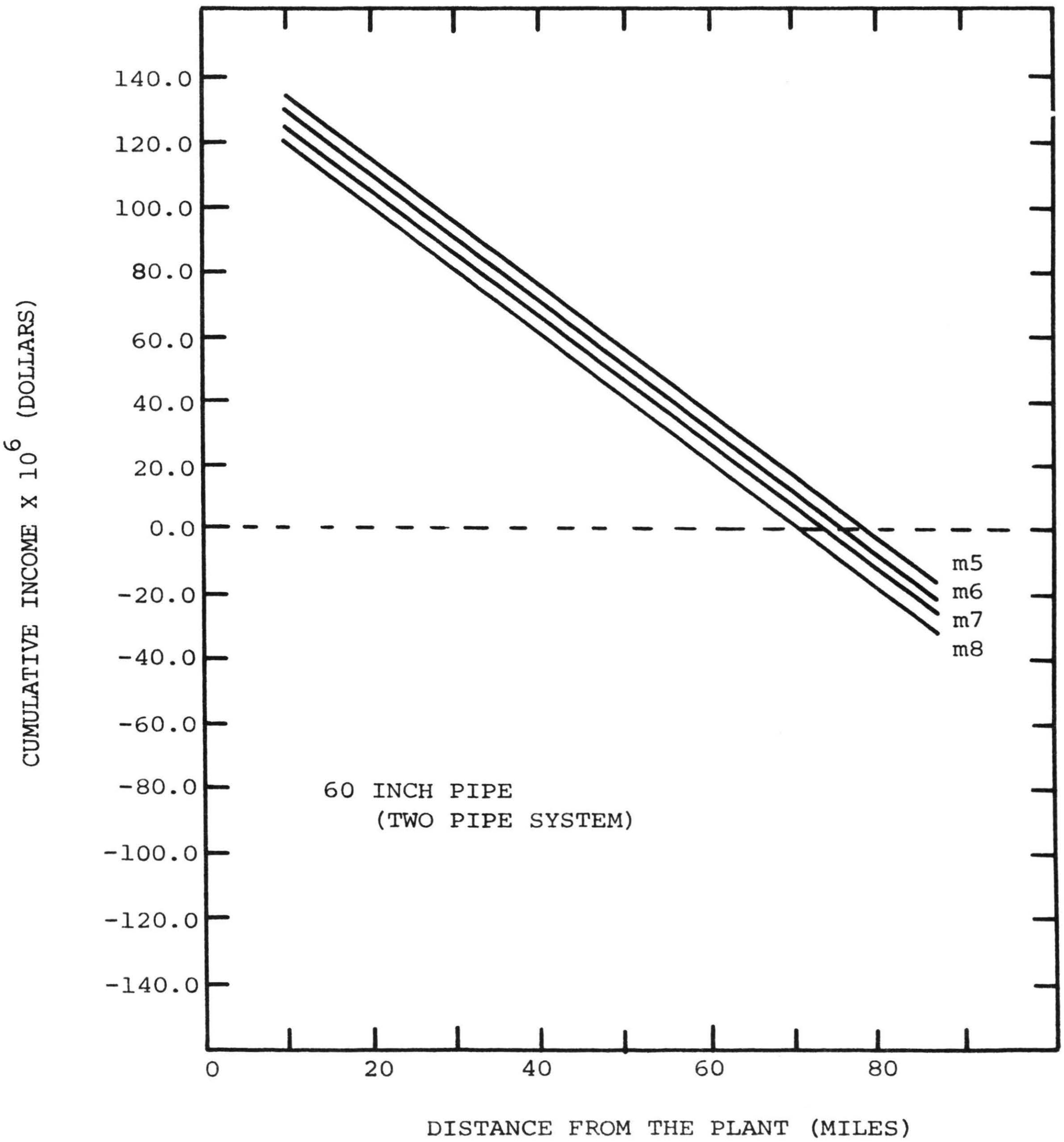

Fig. 21.0. Present Value of Cumulative Income at 10% for a 30 Year Life vs. Years. m5-m8

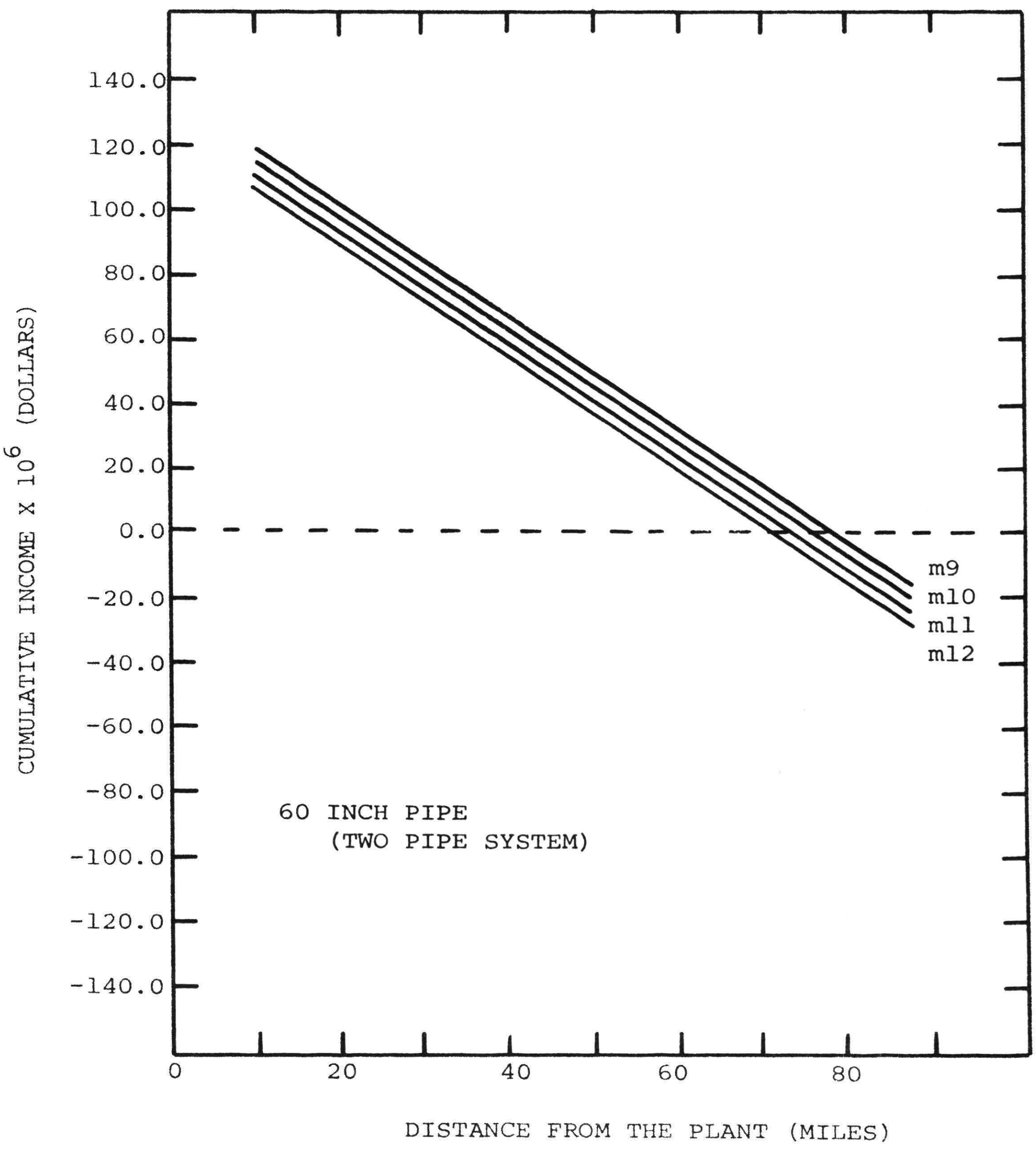

Fig. 22.0. Present Value of Cumulative Income at 10% for a 30 Year Life vs. Years. m9-m12

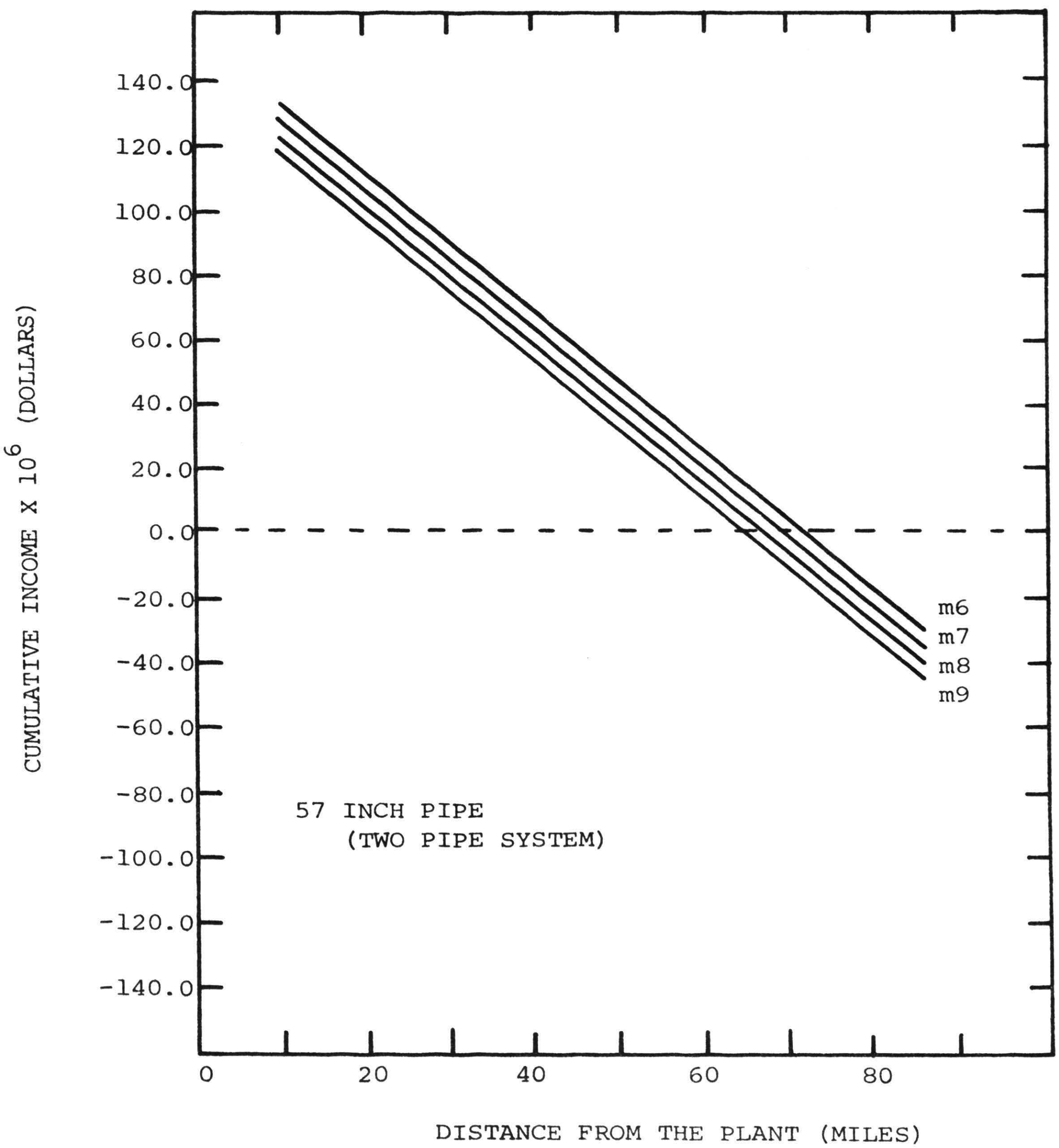

Fig. 23.0. Present Value of Cumulative Income at 10% for a 30 Year Life vs. Years. m6-m9

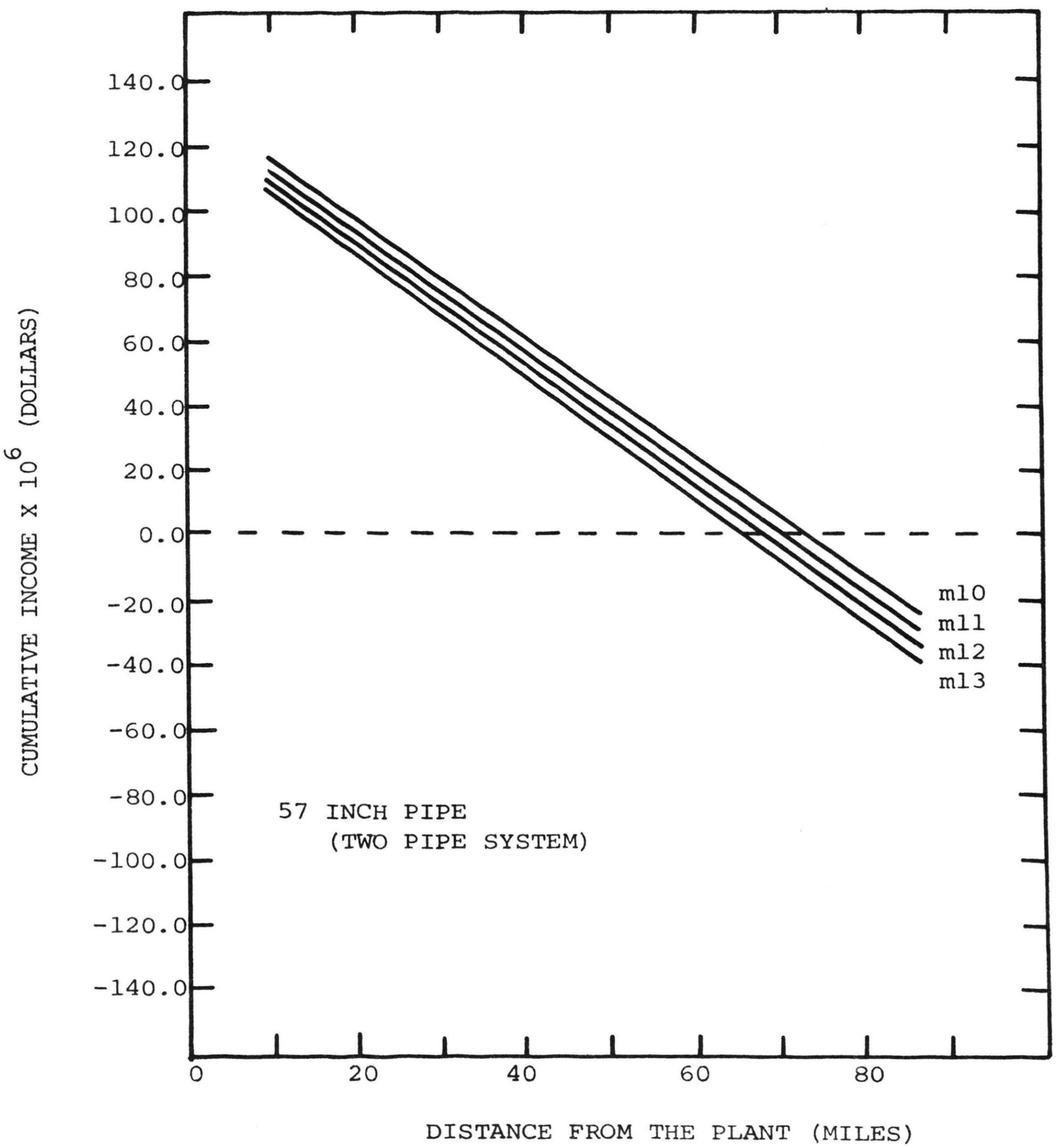

Fig. 24.0. Present Value of Cumulative Income at 10% for a 30 Year Life vs. Years. m10-m13

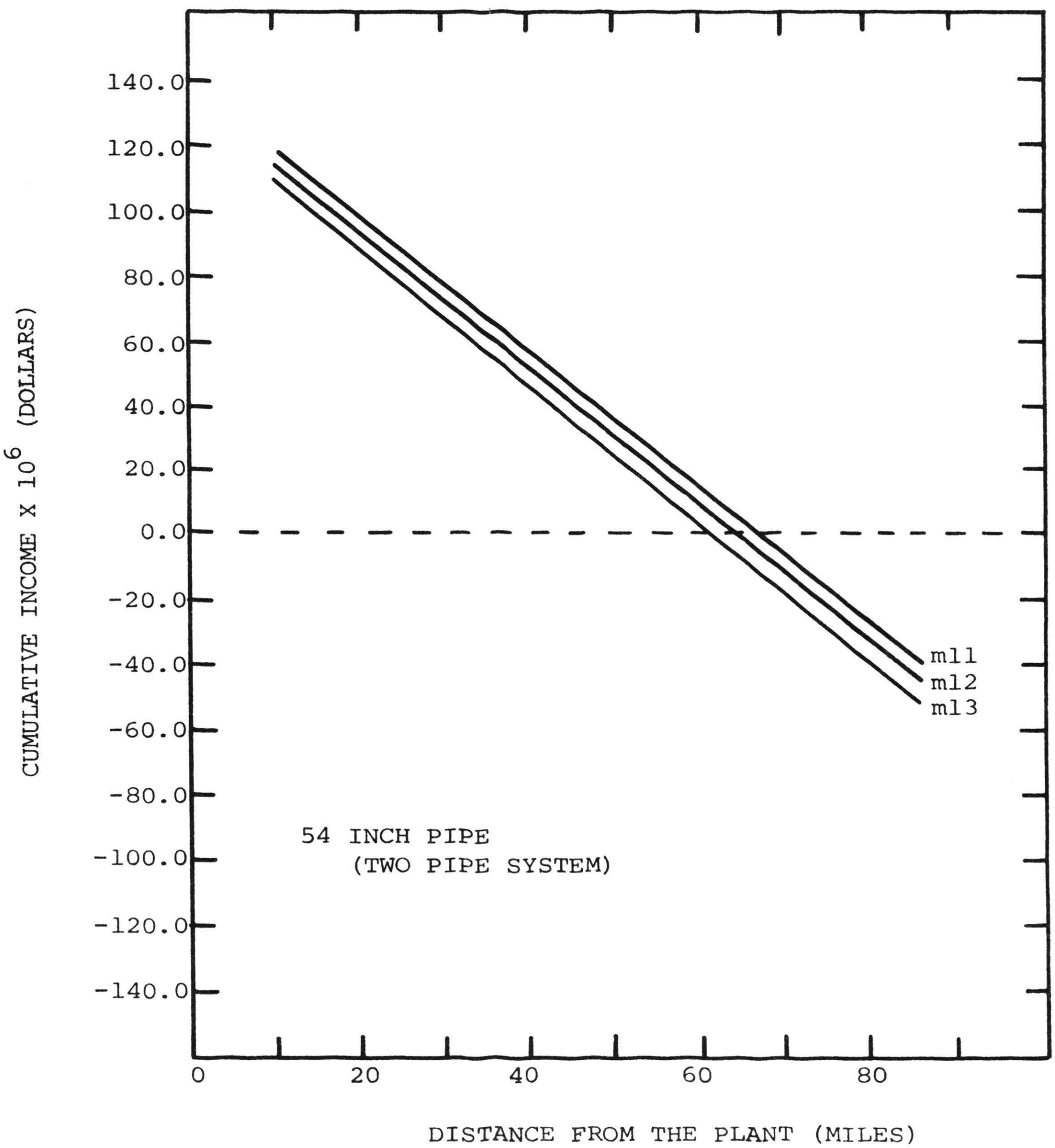

Fig. 25.0. Present Value of Cumulative Income at 10% for a 30 Year Life vs. Years. m11-m13

V. DISCUSSION OF RESULTS

Depending on the mass rate of flow and pipe diameter, it is possible to realize at least a 10% internal rate of return at distances from the load center between 50 and 75 miles. At distances greater than this range internal rates of return less than 10% would be realized. At distances less than this range internal rates of return greater than 10% would be realized.

It must be remembered that the most significant assumption made in this investigation was the fact that the system would operate at full load capacity for the heating period of four months and a cooling period of three months. Hence, these systems are being presented as supplemental in nature to existing heating and refrigeration systems. The heating and cooling network is designed to handle a major portion of the steady load season, which is usually in the middle of the summer and winter seasons. If the systems were to be applied on a year round basis, the load requirements for the local area would have to be determined and the water flow rate adjusted according to the varying load requirements, in variable seasons as the spring and fall. However, even if these systems were used as suggested herein, that is, as supplemental systems, the energy savings and economic benefit would still be quite high.

The efficient utilization of energy from high temperature gas cooled reactors not only has the attractive point of utilizing much of the energy that would be otherwise wasted; but, also the added advantage of conserving fossil fuel resources, that would ordinarily have been required to supply the heating and air conditioning service during high load periods.

The fossil fuel savings would of course be equivalent to the energy consumed by the load center during operation of the waste heat systems. For example, if the load required 3×10^9 BTU/hr for a heating season of 4 months and 100,000 tons of refrigeration for a 3 month cooling season, a savings would be realized for any one of the following sources of energy:

Natural gas

HEATING

$$3.0 \times 10^9 \ \frac{\text{BTU}}{\text{hr}} \times 2880 \text{ hrs} \times \frac{\text{ft}^3}{(1000 \text{ BTU})(.8)} = 10.8 \times 10^9 \ \text{ft}^3$$

COOLING

$$100000 \text{ tons} \times \frac{12000 \text{ BTU}}{\text{HR - ton}} \times 2160 \text{ hrs} \times \frac{\text{ft}^3}{(1000 \text{ BTU})(.5)}$$

$$= 5.18 \times 10^9 \ \text{ft}^3$$

Total = 15.98×10^9 ft^3 natural gas

No. 2 Fuel oil

Using $19110.0 \ \frac{\text{BTU}}{\text{lbm}}$

Savings = 1,749,800 barrels

Electric

Savings = 3,280,000 megawatt-hours

It is clearly seen that considerable quantities of fossile fuels can be conserved, in addition, a profit can be realized by the installation of such a system.

As a suggestion for further study, an investigation into the load following characteristics and the subsequent impact on the economic development would be of considerable interest. In addition the investigation of the utilization of this energy in agricultural and industrial processes (for example, grain drying operations) would merit further study.

VI. CONCLUSIONS

It is possible to service a district heating and cooling network by utilizing the rejected heat from a direct cycle high temperature gas cooled reactor as designed by the General Atomic Company.

The objective of this thesis was to investigate the feasibility of utilizing the rejected energy from the direct cycle HTGR to serve a district heating and cooling network. The objective has been accomplished, insomuch as the results clearly indicate that with the advent of the direct cycle HTGR, waste heat utilization will approach a more realistic solution. New technological advancements such as the direct cycle HTGR will provide the opportunity of increasing our energy utilization efficiency.

Since that which moves the technological society is inventiveness, magnified and implemented by an energy base, it is the techno-sociological responsibility of energy system designers to efficiently and equitably utilize our energy resources. In so doing, an optimized system of environmental, technological and sociological benefits will be realized.

The results of this investigation indicate that the state of the art in reactor design is reaching a point where the maximum energy utilization efficiency may be realized.

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VITA

John J. Blase was born February 13, 1947 in Girardville, Pennsylvania. He was raised in Girardville which is located in the Anthracite coal mining region. After completing his high school education at Cardinal Brennan High School, he attended the Academy of Aeronautics in New York City where he earned his Associate in Applied Science Degree in aircraft design. He also attended Parks College - St. Louis University where he received his B.S. in Aerospace Engineering.

Mr. Blase worked in the capacity of liaison engineer for Grumman Aircraft Engineering Company on the Apollo Project Lunar Module for a period of two years. He also held the position of Mechanical Engineer with the Environmental Protection Agency for two years.

He is President of the UMR Chapter of the American Nuclear Society, Vice President of the Nuclear Engineering and Science Honor Society, and an associate member of the National Society of Professional Engineers. Mr. Blase is married to the former Karen Wolf of St. Louis, Missouri.

APPENDIX A

REVIEW OF LITERATURE

The utilization of low temperature waste heat from steam-electric power plants has always been a difficult task. The temperature of the rejected heat is relatively low (around 105°F), thus making the utilization of this energy quite difficult. There have been significant efforts, however, involved in utilizing waste energy. An entire range of heating[3][18] and agricultural[4] uses have been proposed. Some have met with success and many have not.

A unique approach to the use of this low value energy has been made by W. Martinovsky[13][14] of the Odessa Technical Institute in the Soviet Union. In 1953 Martinovsky proposed[13] the rejection of low value waste heat to a steam jet refrigeration cycle. In his proposal the steam jet cycle did not use water as a refrigerant as is the usual case, instead it was suggested that a freon or similar refrigerant be utilized in the steam jet refrigerating process. The low condenser temperatures of the steam jet cycle limited the use of such a system because of the large heat exchanger surfaces required at the condenser end of the cycle. The utilization of waste energy from steam-electric cycles is indeed worthy of future investigation when one considers the number of such plants in existence.

The advent of high temperature gas cooled reactors as designed by General Atomic, has added a new dimension to the possibilities of utilizing the heat rejected from the nuclear-electric energy cycle. The only helium cooled nuclear reactor in operation in the United States at this time is the 330 MWe unit operated by Public Service Company of Colorado. This unit utilizes a conventional steam-electric cycle, coupled to a helium-water steam generator. A new design under consideration at this time by General Atomic is the direct cycle high temperature gas (helium) cooled reactor[11]. In this machine, the helium is heated in the reactor core and then expanded directly through a gas turbine which consequently turns the electric generator[11]. The attractive feature of this cycle is the temperature at which the waste heat is rejected. Rejection temperatures across the precooler stage of the cycle is from 470°F to 105°F[11]. Immediately it can be seen that this high value waste heat has many utilization possibilities. In fact, much research into the effective utilization of this energy is underway at the General Atomic facility in San Diego, California.

Rejection temperatures in this range could provide sufficiently high temperature input to generate low energy steam which may in turn power a water cycle series of steam jet refrigeration units.[8] This chilled water could in turn be used either in industrial processes or it could provide for a district refrigeration service (air conditioning). Chilled and heated water district heating and cooling systems have been in existence for many years[1], and, therefore, this technological consideration is neither surprising nor new. However, the great distance of nuclear power plants from load centers[18] increases the difficulty involved in transporting heated and chilled water to the load center. The pipeline technology required to move large quantities of water has been available to the oil and natural gas industries for many years[9][17].

The object of this investigation is the determination of the technical and economic feasibility of transporting large quantities of heated and chilled water to a concentrated load center by using the rejected heat from the high temperature gas cooled reactor as the energy source.

APPENDIX B

FORTRAN IV COMPUTER PROGRAM LISTING

```
0001          SUBROUTINE TECH
        C
        C********* TECH DOES ALL PRESSURE DROP AND HEAT TRANSFER CALCULATIONS *********
        C
0002          REAL K1
0003          REAL K2
0004          REAL K3
0005          REAL MLIQ
0006          DIMENSION E(180),T(180)
0007          DIMENSION T1A(100),T2A(100),QBA(100),DISA(100)
0008          DIMENSION T3A(100),T4A(100),HEATA(100)
0009          COMMON AT(10),PR(10),KV(10)
0010          J=1
0011          I=3
0012          DO 1001 L=1,100
0013          T1A(L)=0.0
0014          T2A(L)=0.0
0015          QBA(L)=0.0
0016          DISA(L)=0.0
0017          T3A(L)=0.0
0018          T4A(L)=0.0
0019          HEATA(L)=0.0
0020     1001 CONTINUE
0021          ADIS=0.0
0022          ENTHY=117.95
0023          ENTHW=166.09
0024          PI=3.14115927
0025          I=3
0026          J=1
0027          READ(J,7000)AMHP
0028          READ(J,7003)AA,AE
0029          READ(J,7001)AINC,Z,FF,SV,ENTH1,ENTH3
0030          READ(J,7004)AKW,ANUW,ANPR,K1,K2,K3,N,DA
0031          EE=AE
0032          F=0.0
0033          Q=199270.0
0034          DO 28 I=1,6
0035          READ(J,1010)AT(I),PR(I),KV(I)
0036       28 CONTINUE
0037          DO 20 II=1,N
0038          READ(J,8000)E(II),T(II)
0039       20 CONTINUE
0040          MLIQ=48.0E+06
0041          WRITE(I,8999)
0042          WRITE(I,9000)ENTH1,ENTH3,K1,K2,K3,AKW,ANUW,ANPR,Q,X,FF
0043          GO TO 7
0044        9 CONTINUE
0045          DO 820 IC=1,IA
0046          WRITE(I,9004)T1A(IC),T2A(IC),QBA(IC),T3A(IC),T4A(IC),HEATA(IC),DIS
             -A(IC)
0047          WRITE(7,9007)QBA(IC),HEATA(IC),DISA(IC)
0048      820 CONTINUE
0049          IF(D.LT.60.10)GO TO 3
0050        7 MLIQ=MLIQ-0.50E+06
0051          IF(MLIQ.LT.10.00E+06) GO TO 100
0052          D=63.0
```

```
    3 D=D-3.0
      IF(D.LT.40.0)GO TO 7
      L=0.
      DD=D/12.0
      AREA=(PI*D**2.)/(4.0*144.0)
      VEL=MLIQ/(AREA*62.4)
      AVEL=VEL/3600.
      CALL PRESS(AREA,FF,MLIQ,D,SV,DELP)
      CALL HORSE(DELP,MLIQ,AMHP,HP,PLOC,ENTHP)
      IF(PLOC.LT.10.0)GO TO 7
      DIS=0.0
      ENTHZ=0.0
      ENTHX=0.0
      ENTH2=0.0
      ENTH4=0.0
      ENTHX=ENTHW+ENTHX+ENTHP
      ENTHZ=ENTHY+ENTHZ+ENTHP
      ENTH2=ENTH1+ENTH2+ENTHP
      ENTH4=ENTH3+ENTH4+ENTHP
  120 DIS=DIS+AINC
      IF(DIS.GT.AA) GO TO 9
      ZZ=0.0
      CALL TEMP(E,T,ENTH2,J,N,TIN1)
      CALL TEMP(E,T,ENTH4,J,N,TIN2)
      CALL TEMP(E,T,ENTHX,J,N,TINA)
      CALL TEMP(E,T,ENTHZ,J,N,TIN3)
      QB=(ENTH3-ENTH2)*MLIQ
      QB=QB/12000.0
      HEAT=(ENTHX-ENTHY)*MLIQ
      IF(QB.LT.9000.0) GO TO 3
      IF(DIS.GT.AINC) GO TO 170
      WRITE(I,8998)
      WRITE(I,9001)
      WRITE(I,9002)MLIQ,DELP,D,AVEL,THK
      WRITE(I,9003)HP,PLOC
      WRITE(7,9006)MLIQ,D,PLOC
      IF(DIS.GT.AINC) GO TO 170
      WRITE(I,9005)
      IA=0
  170 CONTINUE
      IA=IA+1
      T3A(IA)=TINA
      T4A(IA)=TINB
      HEATA(IA)=HEAT
      T1A(IA)=TIN1
      DISA(IA)=DIS
      QBA(IA)=QB
      T2A(IA)=TIN2
      L=L+1
      IF(L.GT.52) GO TO 40
      GO TO 50
   40 WRITE(I,8998)
      L=0
   50 CONTINUE
  130 CALL TEMP(E,T,ENTH2,J,N,  TIN1)
      CALL TEMP(E,T,ENTH4,J,N,  TIN2)
```

```
0109           CALL TEMP(E,T,ENTHX,J,N,TINA)
0110           CALL TEMP(E,T,ENTHZ,J,N,TINB)
0111           C=0.0
0112           B=.3
0113           CALL HTRAN(TIN2,K1,K2,K3,VEL,DD,ANUW,ANPR,B,AKW,C,HT2,R1,R2,R3,THK
              -)
0114           CALL HTRAN(TINA,K1,K2,K3,VEL,DD,ANUW,ANPR,B,AKW,C,HTA,R1,R2,R3,THK
              -)
0115           B=.4
0116           C=EE
0117           CALL HTRAN(TIN1,K1,K2,K3,VEL,DD,ANUW,ANPR,B,AKW,C,HT1,R1,R2,R3,THK
              -)
0118           CALL HTRAN(TINB,K1,K2,K3,VEL,DD,ANUW,ANPR,B,AKW,C,HTB,R1,R2,R3,THK
              -)
0119           HTA=HTA*AINC*5280.0/Z
0120           HTB=HTB*AINC*5280.0/Z
0121           HT1=HT1*AINC*5280.0/Z
0122           HT2=HT2*AINC*5280.0/Z
0123           THK=THK*12.0
0124           ENTH2=-(HT1/MLIQ)+ENTH2
0125           ENTH4=-(HT2/MLIQ)+ENTH4
0126           ENTHX=-(HTA/MLIQ)+ENTHX
0127           ENTHZ=-(HTB/MLIQ)+ENTHZ
0128           ADIS=ADIS+AINC/Z
0129           IF(ADIS-(PLOC-.1)) 400,140,140
0130       140 ENTH2=ENTH2+ENTHP
0131           ENTH4=ENTH4+ENTHP
0132           ENTHX=ENTHX+ENTHP
0133           ENTHZ=ENTHZ+ENTHP
0134           ADIS=0.0
0135       400 ZZ=ZZ+1.0
0136           IF(ZZ.GE.Z) GO TO 120
0137           GO TO 130
0138      1010 FORMAT(3F10.5)
0139      7000 FORMAT(F12.3)
0140      7001 FORMAT(6F12.5)
0141      7003 FORMAT(2F12.5)
0142      7004 FORMAT(6F8.5,I3,F6.2)
0143      8000 FORMAT(2F10.3)
0144      8998 FORMAT(1H1,////)
0145      8999 FORMAT(1H1,//////////////////////)
0146      9000 FORMAT('PLANT OUTLET ENTHALPY =',F9.6, ' BTU/LBM',///,'LOAD OUTLET
              -ENTHALPY  =',F9.6, ' BTU/LBM',////,'THERMAL CONDUCTIVITY OF:',//,2
              -0X,'PIPE      =',F8.5, ' BTU/HR-FT-DEGF',/,20X,'INSULATION =',F8.5
              -, ' BTU/HR-FT-DEGF',/,20X,'SOIL       =',F8.5, ' BTU/HR-FT-DEGF',/
              -,20X,'WATER      =',F8.5, ' BTU/HR-FT-DEGF',///,'KINEMATIC VISCOSI
              -TY OF THE WATER =',F6.5, ' FT SQ/HR',///,'PRANDTL NUMBER =',F4.2,/
              -//,'REFRIGERATION AVAILABLE AT THE PLANT =',F7.0,' TONS',///,'NUMB
              -ER OF PIPES IN ONE DIRECTION =',F3.0,///,'PIPE FRICTION FACTOR (MO
              -ODY DETERMINATION) =',F5.3)
0147      9001 FORMAT(' MASS RATE   PRESSURE LOSS PIPE DIA. VELOCITY  INSULATION
              -',/,'  OF FLOW      PER MILE     (INCHES)  (FT/SEC) THICKNESS(IN.)'
              -)
0148      9002 FORMAT(E12.6,2X,E9.3,4X,F5.2,4X,F8.3,4X,F6.3)
0149      9003 FORMAT(/,' HP/PIPE/MILE =',F3.2,' DIS BETWEEN PUMPS =',F5.1,/)
0150      9004 FORMAT(4X,F6.2,7X,F6.2,6X,F9.2,6X,F6.2,6X,F6.2,6X,E12.6,6X,F8.4)
```

```
FORTRAN IV G1  RELEASE 2.0           TECH            DATE = 74093         22/22/16              PAGE 0004

0151          9005 FORMAT(' TEMP LEAVING TEMP LEAVING REFRIGERATION TEMP LEAVING  TEM
                  -P LEAVING       HEAT          DISTANCE FROM  ',/,'   REF PLANT    REF
                  - LOAD       AVAILABLE     HEAT PLANT     HEAT LOAD       AVAILABLE
                  -THE LOAD CENTER        ',/,'     (DEG F)        (DEG F)         (TONS)
                  -     (DEG F)        (DEG F)            (BTU/HR)          (MILES)       ')
0152          9006  FORMAT(E13.6,F5.2,F5.1)
0153           9007 FORMAT(F9.2,E14.6,F6.1)
0154            100 RETURN
0155                END
```

```
FORTRAN IV G1  RELEASE 2.0           PRKV            DATE = 74093         22/22/16              PAGE 0001

0001                SUBROUTINE PRKV(T,PRAN,KINV)
              C
              C********* PRKV DOES A TABLE LOOK UP FOR PRANDTL NUMBER AND KINEMATIC VIS ******
              C
0002                COMMON AT(10),PR(10),KV(10)
0003                DO 10 I=1,6
0004                IF((T.GE.AT(I)).AND.(T.LT.AT(I+1))) GO TO 40
0005             10 CONTINUE
0006             40 A=AT(I+1)
0007                B=AT(I)
0008                PA=PR(I+1)
0009                PB=PR(I)
0010                KA=KV(I+1)
0011                KB=KV(I)
0012                PRAN =((T-B)/(A-B))*(PA-PB)+PB
0013                KINV=((T-B)/(A-B))*(KA-KB)+KB
0014                RETURN
0015                END
```

```
FORTRAN IV G1  RELEASE 2.0           PRESS           DATE = 74093         22/22/16              PAGE 0001

0001                SUBROUTINE PRESS(AREA,FF,MLIQ,D,SV,DELP)
              C
              C********* PRESS CALCULATES PRESSURE DROP PER MILE ****************************
              C
0002                REAL MLIQ
0003                G=MLIQ/AREA
0004                DELP=((FF*5280.)/D)*SV*((G/100000.0)**2)
0005                RETURN
0006                END
```

```
0001          SUBROUTINE TEMP(E,T,ENTH,J,N,TR)
        C
        C********* TEMP IS A TABLE LOOK UP FOR TEMPERATURE GIVEN ENTHALPY **************
        C
0002          DIMENSION E(180),T(180)
0003          NN=N-1
0004          DO 30 I=1,NN
0005          IF((ENTH.GE.E(I)).AND.(ENTH.LT.E(I+1))) GO TO 40
0006       30 CONTINUE
0007       40 TIN=T(I)
0008          EN=E(I)
0009          ENN=E(I+1)
0010          B=T(I+1)
0011          TR=((EN-ENTH)/(EN-ENN))*(B-TIN)+TIN
0012          RETURN
0013          END
```

```
      SUBROUTINE HCPLOT
C
C********* HCPLOT PLOTS THE DATA FROM THE TECH ROUTINE ************************
C
      DIMENSION H(50),R(50),DI(50)
      CALL PENPOS('BLASE',5,0)
      ZA=25.0
      ZB=0.0
      AD=39.0
      GD=63.0
    1 GD=GD-3.0
      IF(GD.LT.AD)GO TO 300
      REWIND 8
      L=200
      LA=15
   30 READ(8)Q,DIA,PLOC
      IF(Q.LT.5.0)GO TO 100
      DO 20 I=1,44
      READ(8)A,B,DI(I)
      H(I)=B*1.0E-07
   20 CONTINUE
      AW=GD+0.5
      AZ=GD-0.5
      IF((DIA.GT.AW).OR.(DIA.LT.AZ))GO TO 30
      L=L+1
      WRITE(3,25)DIA
      IF(L.LT.LA)GO TO 50
      IF(L.EQ.LA)CALL ENDPLT
      L=0
      CALL NEWPLT(0.5,2.0,6.0)
      CALL ORIGIN(0.0,100.0)
      CALL XSCALE(0.0,120.0,4.5)
      CALL YSCALE(ZA,300.0,6.0)
      CALL XAXIS(10.0)
      CALL YAXIS(25.0)
   50 CALL XYPLT(DI,H,44,1,-1)
      GO TO 30
  100 IF(L.LT.LA) CALL ENDPLT
      REWIND 8
      L=200
   40 READ(8)Q,DIA,PLOC
      IF(Q.LT.5.0)GO TO 200
      DO 120 I=1,44
      READ(8)A,B,DI(I)
      R(I)=A*1.0E-03
  120 CONTINUE
      IF((DIA.GT.AW).OR.(DIA.LT.AZ))GO TO 40
      L=L+1
      IF(L.LT.LA) GO TO 150
      IF(L.EQ.LA)CALL ENDPLT
      L=0
      CALL NEWPLT(0.5,2.0,6.0)
      CALL ORIGIN(0.0,25.0)
      CALL XSCALE(0.0,120.0,4.5)
      CALL YSCALE(ZB,75.0,6.0)
      CALL XAXIS(10.0)
```

```
      CALL YAXIS(5.0)
  150 CALL XYPLT(DI,R,44,1,-1)
      GO TO 40
  200 IF(L.LT.LA) CALL ENDPLT
      GO TO 1
  300 CONTINUE
   25 FORMAT(F6.2)
      RETURN
      END
```

```
      SUBROUTINE CASH
C
C********* CASH DOES THE DISCOUNTED CASH FLOW ANALYSIS *************************
C
      REAL MAINT
      REAL MLIQ
      DIMENSION CASINA(50),CASQUA(50),CASINB(50),CASQUB(50),CASINC(50),
     -CASQUC(50),CASINE(50),CASQUE(50),CASINF(50),CASQUF(50)
      DIMENSION REF(100),HEAT(100),DIS(100),COSMA(100),COSMV(100),COSMI(
     -100)
      DIMENSION COSA(50),COSB(50),COSC(50),COSE(50),COSF(50),MAINT(50)
      DIMENSION D1(50),C1(50),C2(50),C3(50),CF(50)
      NA=7
      REWIND NA
      REWIND 8
      COSR=10000000.0
      AN=4.0
      BN=AN/2.0
      A=1.000
      AA=2.0
      CF(4)=AA
      CF(10)=AA
      CF(20)=AA
      CF(30)=AA
      CF(40)=AA
      DO 301 I=1,50
      COSA(I)=0.0
      COSB(I)=0.0
      COSC(I)=0.0
      COSE(I)=0.0
      COSF(I)=0.0
      MAINT(I)=0.0
  301 CONTINUE
      DO 305 I=1,100
      REF(I)=0.0
      HEAT(I)=0.0
      DIS(I)=0.0
      COSMA(I)=0.0
      COSMV(I)=0.0
      COSMI(I)=0.0
  305 CONTINUE
      READ(1,452)Q,QZ
      READ(1,450)PCB,RORB,PCC,RORC,PCP,RORP
      READ(1,451)N,T,APCT,BPCT
      READ(1,103)HH,CC
      READ(1,100)AMHP,AIN,ADIN,PUMCOS
      DO 604 I=1,23
      READ(1,102)D1(I),C1(I),C2(I),C3(I)
  604 CONTINUE
 1000 READ(1,101,END=110)MLIQ,DIA,PLOC
      WRITE(8)MLIQ,DIA,PLOC
      IF(QZ.LT.10.0)GO TO 2000
      WRITE(3,104)
 2000 CONTINUE
      IF(MLIQ.LT.100.0) GO TO 8
      DO 500 I=1,44
```

```
0052            READ(1,105)REF(I),HEAT(I),DIS(I)
0053            WRITE(8)REF(I),HEAT(I),DIS(I)
0054       600  CONTINUE
0055            CALL ZIP(D1,C1,C2,C3,DIA,COST1,COST2,COST3)
0056            DO 602 I=1,44
0057            COSMAX=COST1*DIS(I)
0058            COSAVG=COST2*DIS(I)
0059            COSMIN=COST3*DIS(I)
0060            PNO=DIS(I)/PLOC
0061            IX=PNO
0062            X2=IX
0063            X3=X2+1.0
0064            COSPUM=X3*PUMCOS*AMHP
0065            COSMA(I)=AN*(COSPUM+COSMAX)+COSR
0066            COSMV(I)=AN*(COSPUM+COSAVG)+COSR
0067            COSMI(I)=AN*(COSPUM+COSMIN)+COSR
0068            MAINT(I)=((COSPUM*.02)+(X3*27.0*(HH+CC)))*AN+0.02*COSMV(I)
0069       602  CONTINUE
0070            REV=HH*HEAT(4)*A*BN/1000000.0
0071            RREV=CC*REF(4)*CF(4)*A*BN*12000.0/1000000.0
0072            J=4
0073            CALL EXACT(PCB,RORB,PCC,RORC,PCP,RORP,N,COSMV(J),AIN,ADIN,REV,
               -RREV,MAINT(J),CASINA,CASOUA)
0074            REV=HH*HEAT(10)*A*BN/1000000.0
0075            RREV=CC*REF(10)*A*BN*CF(10)*12000.0/1000000.0
0076            J=10
0077            CALL EXACT(PCB,RORB,PCC,RORC,PCP,RORP,N,COSMV(J),AIN,ADIN,REV,
               -RREV,MAINT(J),CASINB,CASOUB)
0078            REV=HH*HEAT(20)*A*BN/1000000.0
0079            RREV=CC*REF(20)*CF(20)*A*BN*12000.0/1000000.0
0080            J=20
0081            CALL EXACT(PCB,RORB,PCC,RORC,PCP,RORP,N,COSMV(J),AIN,ADIN,REV,
               -RREV,MAINT(J),CASINC,CASOUC)
0082            REV=HH*HEAT(30)*A*BN/1000000.0
0083            RREV=CC*REF(30)*CF(30)*A*BN*12000.0/1000000.0
0084            J=30
0085            CALL EXACT(PCB,RORB,PCC,RORC,PCP,RORP,N,COSMV(J),AIN,ADIN,REV,
               -RREV,MAINT(J),CASINE,CASOUE)
0086            REV=HH*HEAT(40)*A*BN/1000000.0
0087            RREV=CC*REF(40)*CF(40)*A*BN*12000.0/1000000.0
0088            J=40
0089            CALL EXACT(PCB,RORB,PCC,RORC,PCP,RORP,N,COSMV(J),AIN,ADIN,REV,
               -RREV,MAINT(J),CASINF,CASOUF)
0090            IF(QZ.LT.10.0)GO TO 2001
0091            WRITE(3,805)
0092            WRITE(3,800)
0093            WRITE(3,801)MLIQ,DIA,PLOC
0094            WRITE(NA)MLIQ,DIA,PLOC
0095            WRITE(3,802)
0096            WRITE(3,803)
0097            WRITE(3,804)
0098      2001  CONTINUE
0099            YA=CASINA(N)-CASOUA(N)
0100            YB=CASINB(N)-CASOUB(N)
0101            YC=CASINC(N)-CASOUC(N)
0102            YE=CASINE(N)-CASOUE(N)
```

```
            YF=CASINF(N)-CASOUF(N)
            IYEAR =0
            DO 506 I=1,N
            IYEAR=IYEAR+1
            IF(QZ.LT.10.0)GO TO 2002
            WRITE(3,911)IYEAR,CASOUA(I),CASINA(I),CASOUB(I),CASINB(I),CASOUC(I
           -),CASINC(I),CASOUE(I),CASINE(I),CASOUF(I),CASINF(I)
      2002 CONTINUE
            WRITE(NA)   IYEAR,CASOUA(I),CASINA(I),CASOUB(I),CASINB(I),CASOUC(I
           -),CASINC(I),CASOUE(I),CASINE(I),CASOUF(I),CASINF(I)
       506 CONTINUE
            WRITE(3,805)
            ALIN=ADIN*100.0
            WRITE (3,10)ALIN,N
            WRITE(3,1)YA,YB,YC,YE,YF
            GO TO 1000
       110 MLIQ=0.0
            DIA=0.0
            PLOC=0.0
            WRITE(NA)MLIQ,DIA,PLOC
            CALL CFLOT(N)
         1 FORMAT(17X,1PE12.5,4(12X,1PE12.5))
         2 FORMAT(//////)
        10 FORMAT(14X,'PRESENT VALUE OF INCOME AT ',F4.1,' PER CENT AND A LIF
           -E OF',I3,' YEARS',/)
       100 FORMAT(F7.1,2F5.4,F5.1)
       101 FORMAT(E13.6,F5.2,F5.2)
       102 FORMAT(F9.2,3F10.2)
       103 FORMAT(2F7.1)
       104 FORMAT(1H1)
       105 FORMAT(F9.2,1X,E13.6,F6.1)
       450 FORMAT(6F6.4)
       451 FORMAT(I4,3F6.4)
       452 FORMAT(2F6.2)
       800 FORMAT(1X ,'MASS RATE OF FLOW',20X,'PIPE DIAMETER',15X,'DISTANCE B
           -ETWEEN PUMPS',/,6X,'(LBM/HR)',26X,'(INCHES)',26X,'(MILES)',/)
       801 FORMAT(1X,E13.6,28X,F5.2,28X,F5.2,///)
       802 FORMAT(10(8X,'CASH'))
       803 FORMAT(8X,'OUT',10X,'IN',4(9X,'OUT          IN'))
       804 FORMAT(2X,'YEAR (10 MI)       (10 MI)',5X,'(25 MI)      (25 MI)',5X,
           -'(50 MI)      (50 MI)',5X,'(75 MI)      (75MI)',5X,
           -'(100 MI)     (100 MI)')
       805 FORMAT(////)
       911 FORMAT(I5,10(1PE12.5))
         8 RETURN
            END
```

```
      SUBROUTINE EXACT(PCB,RORB,PCC,RORC,PCP,RORP,N,CI,AIN,ADIN,REV,
     -RREV,MAINT,CASIN,CASOUT)
C
C********* EXACT DOES THE DEPRECIATION SCHEME, TAX CALCULATIONS AND DISCOUNTING
C CALCULATIONS INCLUDING INFLATION FACTORS ************************************
C
      DIMENSION CASOUT(50),CASIN(50),YEAR(50)
      REAL MAINT
      CRF=ADIN*((1.0+ADIN)**N/(((1.0+ADIN)**N)-1.0)
      ADEP=CRF*CI
      TR=0.5
      ASUM=0.0
      BSUM=0.0
      PTP=.02
      YRST=N
      BDEP=CI/YRST
      PCT=(BDEP/CI)*2.0
      ROB=PCB*RORB*CI
      ROC=PCC*RORC*CI
      ROP=PCP*RORP*CI
      TRO=ROB+ROC+ROP
      TAXOUT=CI*PTP
      CA=CI
      DO 10 I=1,N
      YEAR(I)=PCT*CA
      IF(REV.GT.10000.)GO TO 40
      WRITE(3,101)YEAR(I)
   40 CONTINUE
      CA=CA-YEAR(I)
      M=I
      IF((CA/(N-I)-YEAR(I)))12,200,200
   12 CONTINUE
   10 CONTINUE
  200 CONTINUE
      X=M
      RBD=CA/X
      L=M+1
      DO 20 I=M,N
      YEAR(I)=RBD
      IF(REV.GT.10000.)GO TO 50
      WRITE(3,101)YEAR(I)
   50 CONTINUE
   20 CONTINUE
      DO 30 I=1,N
      ES=(1.0+AIN)**I
      PWF=1.0/((1.0+ADIN)**I)
      CALL PWRTH(REV,RREV, I ,AIN,ADIN,MAINT,CASI      ,BMAINT)
      FTAX=TR*(((REV+RREV)*ES)-(MAINT*ES+YEAR(I)+ROB+TAXOUT))
      FEDTAX=FTAX*PWF
      PRTX=TAXOUT*PWF
      DTR=TRO*PWF
      CASOU      =FEDTAX+PRTX+BMAINT+DTR+ADEP
      IF(REV.GT.10000.)GO TO 60
      WRITE(3,100)CASI,FEDTAX,PRTX,BMAINT,DTR,ADEP
   60 CONTINUE
      ASUM=ASUM+CASOU
```

```
FORTRAN IV G LEVEL  21                  ZIP                DATE = 74094          01/00/19             PAGE 0001

               SUBROUTINE ZIP(D,C1,C2,C3,DIA,COSTA,COSTB,COSTC)
          C
          C********* ZIP DOES A TABLE LOOK UP FOR PIPE COSTS *****************************
          C
               DIMENSION C1(50),C2(50),C3(50),D(50)
               DO 20 I=1,22
               IF((DIA.GE.D(I)).AND.(DIA.LT. D(I+1)))GO TO 30
            20 CONTINUE
            30 A=C1(I)
               B=C2(I)
               C=C3(I)
               DD=C1(I+1)
               E=C2(I+1)
               F=C3(I+1)
               G=D(I)
               H=D(I+1)
               COSTA=(A+(((DD-A)/(H-G))*(DIA-G)))*1000.0
               COSTB=(B+(((E-B)/(H-G))*(DIA-G)))*1000.0
               COSTC=(C+(((F-C)/(H-G))*(DIA-G)))*1000.0
               RETURN
               END
```

```
FORTRAN IV G LEVEL  21                  EXACT              DATE = 74094          01/00/19             PAGE 0002

               BSUM=BSUM+CASI
               CASOUT(I)=ASUM
               CASIN(I)=BSUM
            30 CONTINUE
           100 FORMAT(5X,6F10.2)
           101 FORMAT(5X,F10.2)
               RETURN
               END
```

```
FORTRAN IV G LEVEL  21                  AWRTH              DATE = 74094          01/00/19             PAGE 0001

               SUBROUTINE AWRTH(K,AAIN,RR,ARR)
          C
          C********* AWRTH IS A ROUTINE THAT DOES THE PRESENT WORTH CALCULATIONS *********
          C
               YEARS=K
               PWF=1.0/((1.0+AAIN)**YEARS)
               ARR=RR*PWF
               RETURN
               END
```

```
0001          SUBROUTINE CPLOT(N)
        C
        C********** CPLOT PLOTS THE DATA FROM CASH *************************************
        C
0002          DIMENSION A(20),B(20),C(20)
0003          DIMENSION IYEAR(50),COSA(50),ATOTAL(50),COSB(50),BTOTAL(50),
             -COSC(50),CTOTAL(50),COSE(50),ETOTAL(50),COSF(50),FTOTAL(50)
0004          DIMENSION YEAR(50),AD(50)
0005          REAL MLIQ
0006          CALL PENPOS('BLASE',5,0)
0007          NA=7
0008          ZD=39.0
0009          DG=63.0
0010       21 REWIND NA
0011          L=0
0012          K=0
0013          M=10
0014          DG=DG-3.0
0015          AG=DG+0.5
0016          BG=DG-0.5
0017       40 READ(NA)MLIQ,DIA,PLOC
0018          IF(MLIQ.LT.1.0) GO TO 50
0019          DO 10 I=1,N
0020          READ(NA)IYEAR(I),COSA(I),ATOTAL(I),COSB(I),BTOTAL(I),COSC(I),
             -CTOTAL(I),COSE(I),ETOTAL(I),COSF(I),FTOTAL(I)
0021          COSA(I)=COSA(I)*1.0E-06
0022          COSB(I)=COSB(I)*1.0E-06
0023          COSC(I)=COSC(I)*1.0E-06
0024          COSE(I)=COSE(I)*1.0E-06
0025          COSF(I)=COSF(I)*1.0E-06
0026          ATOTAL(I)=ATOTAL(I)*1.0E-06
0027          BTOTAL(I)=BTOTAL(I)*1.0E-06
0028          CTOTAL(I)=CTOTAL(I)*1.0E-06
0029          ETOTAL(I)=ETOTAL(I)*1.0E-06
0030          FTOTAL(I)=FTOTAL(I)*1.0E-06
0031          YEAR(I)=IYEAR(I)
0032       10 CONTINUE
0033          IF((DIA.GT.AG).OR.(DIA.LT.BG))GO TO 40
0034          WRITE(3,27)DIA
0035          IF(M.GT.1)GO TO 30
0036          CALL NEWPLT(0.5,2.0,6.0)
0037          CALL ORIGIN(0.0,0.0)
0038          CALL YSCALE(0.0,710.0,4.5)
0039          X=N
0040          CALL XSCALE(0.0,X,4.5)
0041          CALL XAXIS(5.0)
0042          CALL YAXIS(25.0)
0043          CALL  XYPLT(YEAR,COSA,N,1,1)
0044          CALL  XYPLT(YEAR,COSB,N,1,2)
0045          CALL  XYPLT(YEAR,COSC,N,1,3)
0046          CALL  XYPLT(YEAR,COSE,N,1,4)
0047          CALL  XYPLT(YEAR,COSF,N,1,5)
0048          CALL  XYPLT(YEAR,ATOTAL,N,1,6)
0049          CALL  XYPLT(YEAR,BTOTAL,N,1,7)
0050          CALL  XYPLT(YEAR,CTOTAL,N,1,8)
0051          CALL  XYPLT(YEAR,ETOTAL,N,1,11)
```

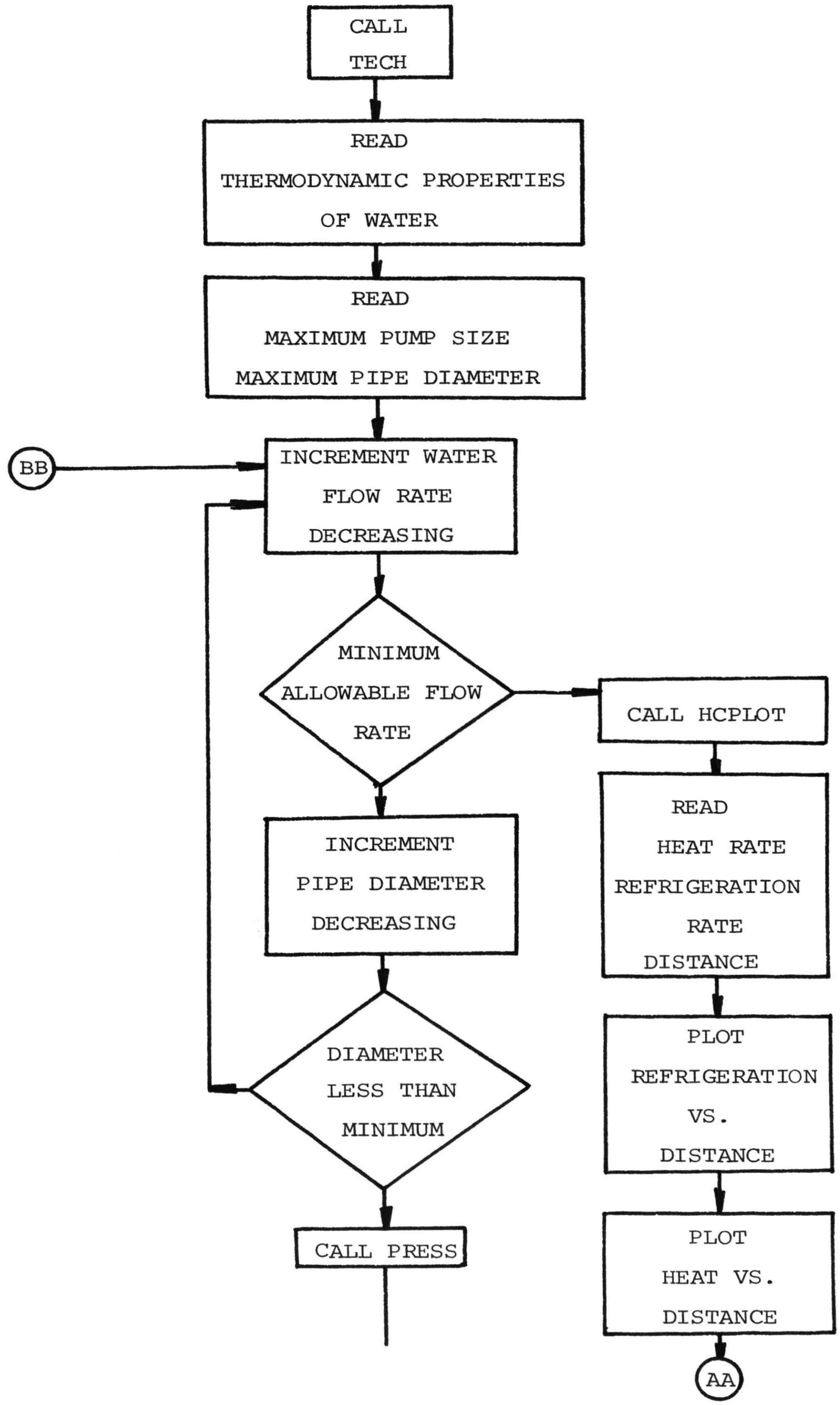
```
      CALL  XYPLT(YEAR,FTOTAL,N,1,12)
      CALL  ENDPLT
   30 CALL  FINAL(COSA(N),ATOTAL(N),COSB(N),BTOTAL(N),COSC(N)
     -,CTOTAL(N),COSE(N),ETOTAL(N),COSF(N),FTOTAL(N),A,B,C)
      DO 32 I=1,5
      AD(I)=C(I)-B(I)
   32 CONTINUE
      KSET=1
      K=K+1
      IF (L.LT.1)GO TO 20
      IF(K.LT.10)GO TO 70
      IF(K.GE.10)CALL ENDPLT
      KSET=2
      K=0
   20 CONTINUE
      L=L+1
      CALL  NEWPLT(0.5,5.5,6.0)
      CALL  ORIGIN(0.0,0.0)
      CALL  XSCALE(0.0,101.0,4.5)
      CALL  YSCALE(-160.0,160.0,6.0)
      CALL  XAXIS(10.0)
      CALL  YAXIS(20.0)
      J=5
      NN=K
      NK=K
   70 CONTINUE
      CALL  XYPLT(A,AD,J,1,NN)
      GO TO 40
   50 CONTINUE
      IF(KSET.EQ.2)GO TO 80
      CALL  ENDPLT
   80 CONTINUE
      IF(DG-ZZ)28,21,21
   28 CONTINUE
      CALL  LSTPLT
   27 FORMAT(F6.2)
      RETURN
      END
```

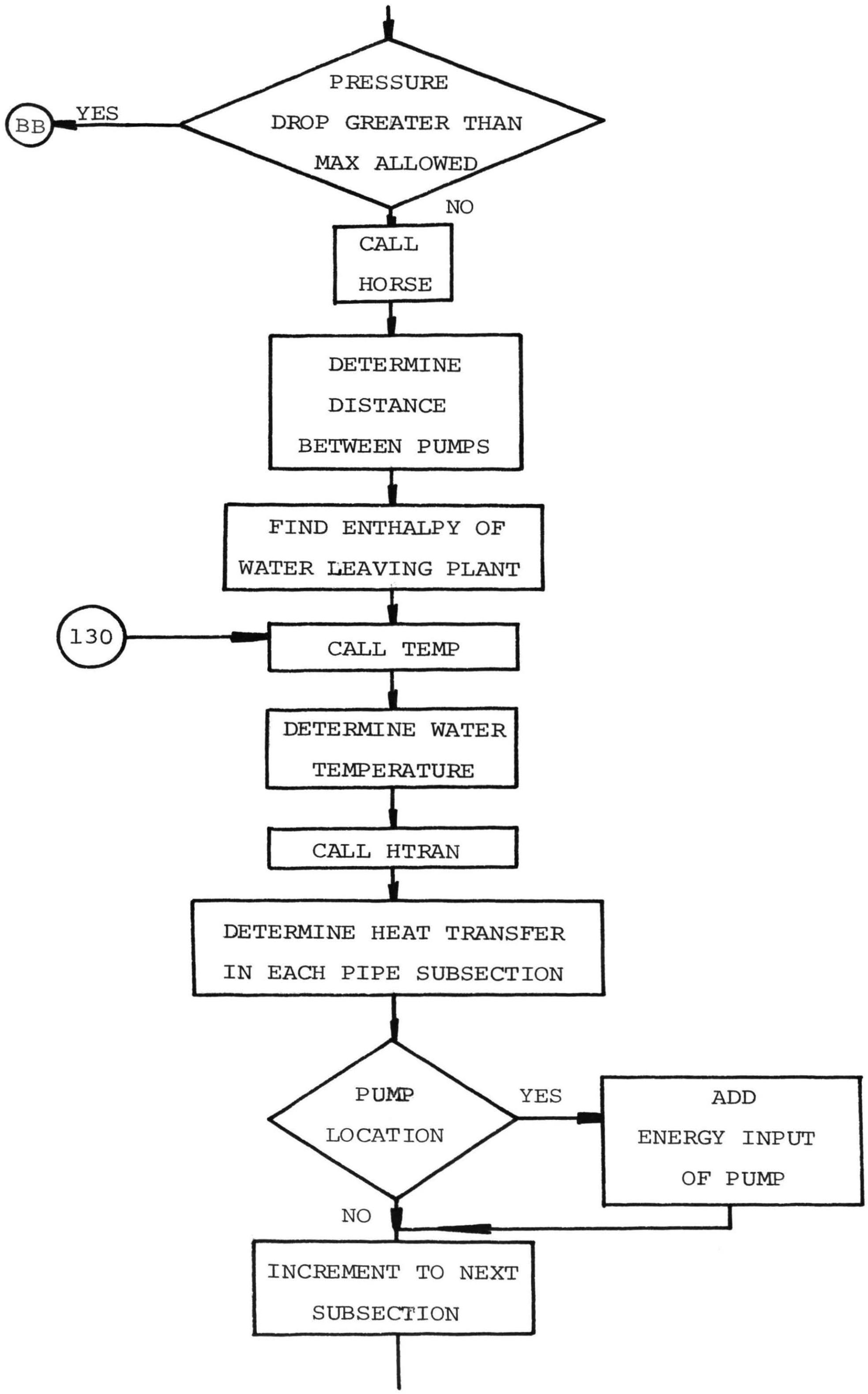
```
FORTRAN IV G LEVEL  21                FINAL              DATE = 74094          01/00/19             PAGE 0001

0001            SUBROUTINE FINAL(COSA,ATOTAL,COSB,BTOTAL,COSC,CTOTAL,COSE,ETOTAL
               -,COSF,FTOTAL,DIS,COST,TOTAL)
          C
          C********* FINAL ARRANGES SCALARS INTO VECTOR FORMS FOR THE PLOTTER ************
          C
0002            DIMENSION DIS(20),COST(20),TOTAL(20)
0003            J=0
0004            J=J+1
0005            DIS(J)=10.0
0006            COST(J)=COSA
0007            TOTAL(J)=ATOTAL
0008            J=J+1
0009            DIS(J)=25.0
0010            COST(J)=COSB
0011            TOTAL(J)=BTOTAL
0012            J=J+1
0013            DIS(J)=50.0
0014            COST(J)=COSC
0015            TOTAL(J)=CTOTAL
0016            J=J+1
0017            DIS(J)=75.0
0018            COST(J)=COSE
0019            TOTAL(J)=ETOTAL
0020            J=J+1
0021            DIS(J)=100.0
0022            COST(J)=COSF
0023            TOTAL(J)=FTOTAL
0024            RETURN
0025            END
```

```
FORTRAN IV G LEVEL  21                PWRTH              DATE = 74094          01/00/19             PAGE 0001

0001            SUBROUTINE PWRTH(REV,RREV,   K   ,AIN,ADIN,MAINT,DZ,DM)
          C
          C********* PWRTH DOES PRESENT WORTH AND COMPOUND AMOUNT CALCULATIONS ***********
          C
0002            REAL MAINT
0003            PWF=1.0/((1+ADIN)**K)
0004            CAF=(1.0+AIN)**K
0005            DDVH=REV*CAF*PWF
0006            DDVR=RREV*CAF*PWF
0007            DM=MAINT*CAF*PWF
0008            DZ=DDVH+DDVR
0009            RETURN
0010            END
```

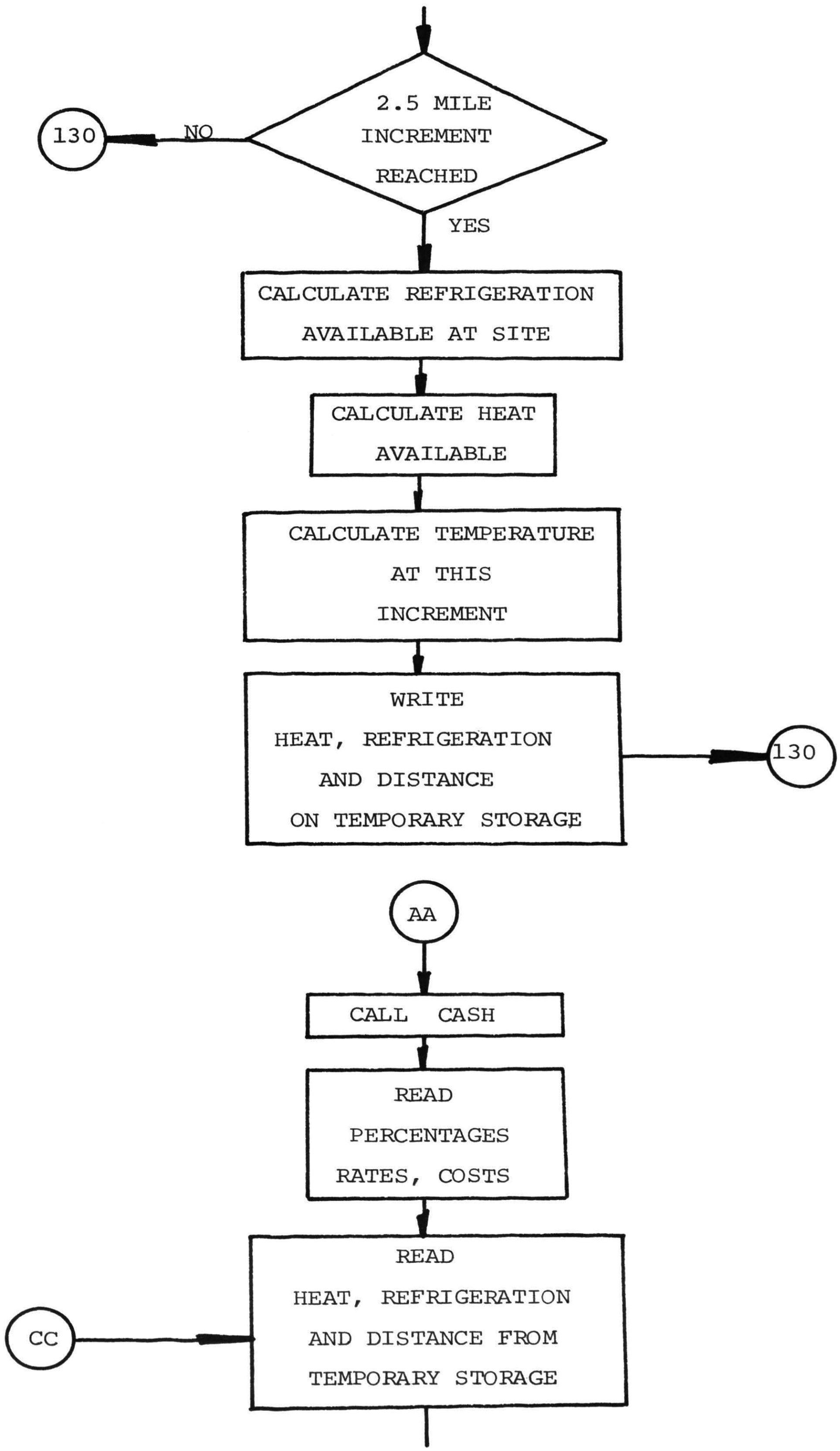
APPENDIX C

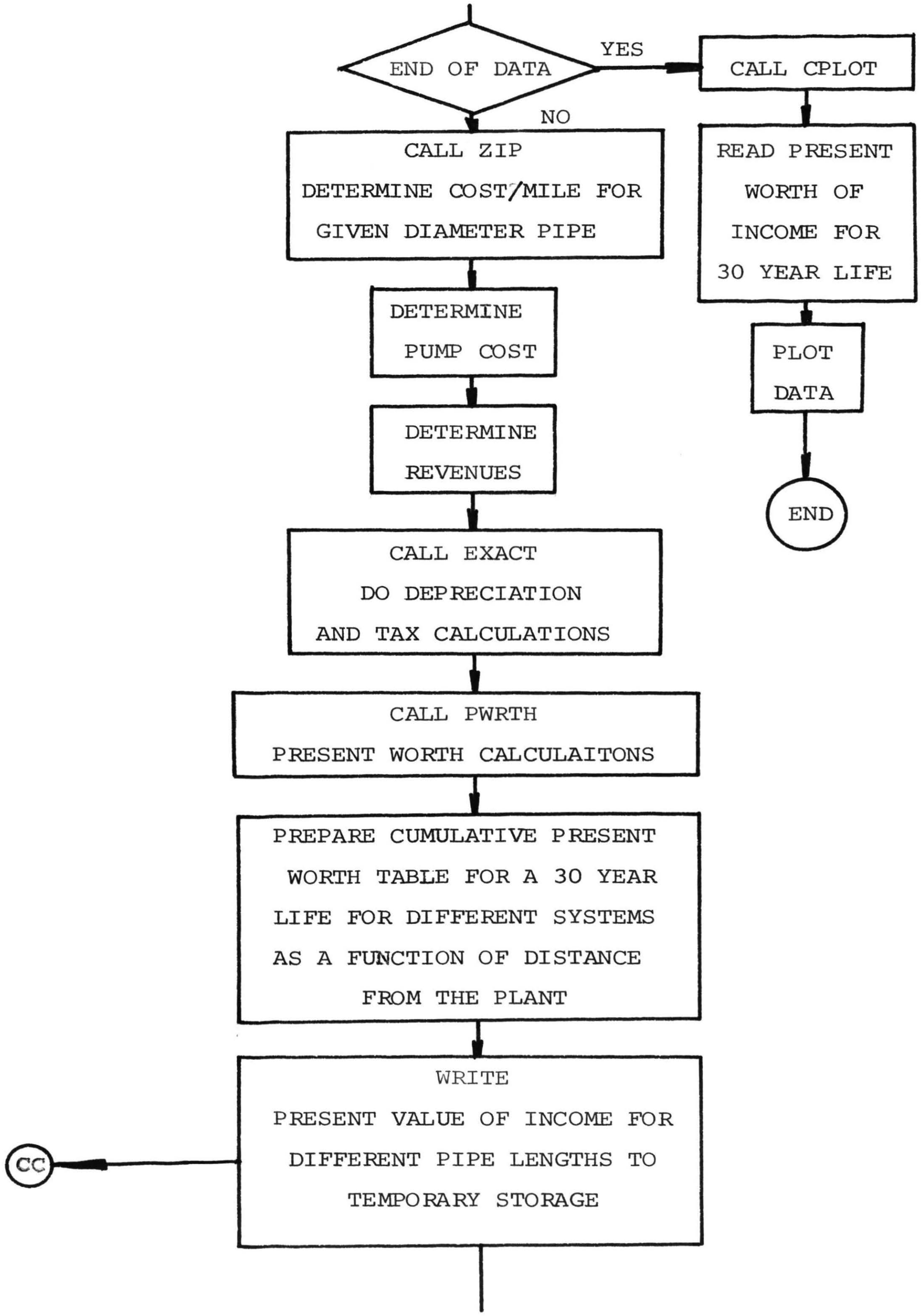
COMPUTER PROGRAM FLOW CHART


CALL TECH
READ THERMODYNAMIC PROPERTIES OF WATER
READ MAXIMUM PUMP SIZE MAXIMUM PIPE DIAMETER
BB
INCREMENT WATER FLOW RATE DECREASING
MINIMUM ALLOWABLE FLOW RATE
CALL HCPLOT
INCREMENT PIPE DIAMETER DECREASING
READ HEAT RATE REFRIGERATION RATE DISTANCE
DIAMETER LESS THAN MINIMUM
PLOT REFRIGERATION VS. DISTANCE
CALL PRESS
PLOT HEAT VS. DISTANCE
AA



PRESSURE DROP GREATER THAN MAX ALLOWED
YES
BB
NO
CALL HORSE
DETERMINE DISTANCE BETWEEN PUMPS
FIND ENTHALPY OF WATER LEAVING PLANT
130
CALL TEMP
DETERMINE WATER TEMPERATURE
CALL HTRAN
DETERMINE HEAT TRANSFER IN EACH PIPE SUBSECTION
PUMP LOCATION
YES
ADD ENERGY INPUT OF PUMP
NO
INCREMENT TO NEXT SUBSECTION


2.5 MILE INCREMENT REACHED
NO
130
YES
CALCULATE REFRIGERATION AVAILABLE AT SITE
CALCULATE HEAT AVAILABLE
CALCULATE TEMPERATURE AT THIS INCREMENT
WRITE HEAT, REFRIGERATION AND DISTANCE ON TEMPORARY STORAGE
130
AA
CALL CASH
READ PERCENTAGES RATES, COSTS
READ HEAT, REFRIGERATION AND DISTANCE FROM TEMPORARY STORAGE
CC


END OF DATA
YES
NO
CALL CPLOT
READ PRESENT WORTH OF INCOME FOR 30 YEAR LIFE
PLOT DATA
END
CALL ZIP
DETERMINE COST/MILE FOR GIVEN DIAMETER PIPE
DETERMINE PUMP COST
DETERMINE REVENUES
CALL EXACT
DO DEPRECIATION AND TAX CALCULATIONS
CALL PWRTH
PRESENT WORTH CALCULAITONS
PREPARE CUMULATIVE PRESENT WORTH TABLE FOR A 30 YEAR LIFE FOR DIFFERENT SYSTEMS AS A FUNCTION OF DISTANCE FROM THE PLANT
WRITE
PRESENT VALUE OF INCOME FOR DIFFERENT PIPE LENGTHS TO TEMPORARY STORAGE
CC

APPENDIX D

SAMPLE CASH FLOW PROBLEM

The following is a sample problem demonstrating the technique used in the discounted cash flow analysis in the economics section of this investigation.

Given:

Capital investment	= \$1000.00
Revenue	= \$2000.00/year
Maintenance & Operating costs	= \$1000.00/year
Inflation factor	= 4.5%
Discount factor	= 10%
Tax rate	= 50%
Property tax rate	= 2%

Find:

The present value net cumulative profit at 10% for a 10 year life.

Straight line depreciation rate:

$$DR = \frac{1}{10 \text{ years}}$$

$$= 10\%$$

Dual declining balance rate:

$$DDR = 2.0 \times DR$$

$$= 20\%$$

The following table is a dual declining balance depreciation scheme which will be used for the tax calculations.

DDB = DDR x Undepreciated balance

where

DDB = Depreciation expense

$$DDB(1) = (.2)(1000.0) = 200.00$$

$$DDB(2) = (.2)(1000.0 - 200.0) = 160.00$$

$$DDB(3) = (.2)(800.00 - 160.0) = 128.00$$

$$DDB(4) = (.2)(640.00 - 128.0) = 102.40$$

$$DDB(5) = (.2)(512.00 - 102.4) = 81.92$$

SWITCH TO STRAIGHT LINE SCHEME

$$DDB(6) = \frac{409.60 - 81.92}{5 \text{ years}} = 65.54$$

$$DDB(7) = 65.54$$

$$DDB(8) = 65.54$$

$$DDB(9) = 65.54$$

$$DDB(10) = 65.54$$

FINANCING EXPENSES/$1000.00 Capital Investment

The project will be financed by:

30% Bonds @ 7% interest

30% Common @ 14% interest

40% Preferred @ 7% interest

Return on Bonds

ROB = Per cent bonds x interest rate x captical investment

= .30 x .07 x 1000.00

= 21.00/year

Return on Common

ROC = Per cent common x interest rate x captical investment

= .30 x .14 x 1000.00

= 42.00/year

Return on Preferred

ROP = Per cent preferred x interest rate x capital investment

= .40 x .07 x 1000.00

= 28.00/year

Total return/$1000.00 Capital Investment

TRO = ROB + ROC + ROP

= 91.00

Property tax/$1000.00 Capital Investment

PRTX = Tax rate x capital investment

= .02 x 1000.00

= 20.00/year

Table D1.0. Schedule for Tax Calculations.

YEAR	SPCA $(1 + i)^n$	MAINT + OP (escalated)	REVENUE (escalated)	DDB	BOND Interest
1	1.045	1045.00	2090.00	200.00	21.00
2	1.092	1092.00	2184.00	160.00	21.00
3	1.141	1141.00	2282.00	128.00	21.00
4	1.192	1192.00	2384.04	102.40	21.00
5	1.246	1246.00	2492.36	81.92	21.00
6	1.302	1302.00	2604.52	65.54	21.00
7	1.360	1360.00	2721.72	65.54	21.00
8	1.422	1422.00	2844.30	65.54	21.00
9	1.486	1486.00	2972.18	65.54	21.00
10	1.552	1552.97	3105.94	65.54	21.00

Where

SPCA = single payment compound amount factor

escalated = adjusted by SPCA for a 4.5% inflation

Income tax

TAX(N) = Tax rate (revenue - bond interest - property tax - maintenance and operating - depreciation)

Example

$$\text{Tax}(1) = .50(2090.00 - 21.00 - 1045.00 - 200.00)$$
$$= 402.00$$

Table D2.0. Yearly Tax.

YEAR	TAX
1	402.00
2	445.37
3	485.67
4	524.54
5	561.54
6	597.85
7	627.15
8	657.78
9	689.77
10	723.21

Capital recovery

$$CR = \text{Capital investment } \left(\frac{i(1 + i)^n}{(1 + i)^{n-1}}\right)$$

$$= 1000.00 \times .16275$$

$$= 162.75$$

Table D3.0. Face Value Cash.

YEAR	REVENUE	TAX	TOTAL INTEREST + DIVIDENDS	PROP. TAX	MAINT OP	SPCA
1	2090.00	402.00	91.00	20.00	1045.00	1.045
2	2184.00	445.37	91.00	20.00	1092.00	1.092
3	2282.20	485.67	91.00	20.00	1141.66	1.141
4	2385.04	524.54	91.00	20.00	1192.52	1.192
5	2492.36	561.63	91.00	20.00	1246.18	1.246
6	2604.52	597.85	91.00	20.00	1302.26	1.302
7	2721.72	627.15	91.00	20.00	1360.86	1.360
8	2844.20	657.78	91.00	20.00	1422.10	1.422
9	2972.18	689.77	91.00	20.00	1486.09	1.486
10	3105.94	723.24	91.00	20.00	1552.97	1.552

Table D4.0. Present Worth at Time 0. Discounted at 10%.

YEAR	REVENUE	TAX	INTEREST + DIVIDENDS	PROP. TAX	MAINT OP
1	1900.00	365.45	82.73	18.18	950.01
2	1804.06	368.05	75.21	16.53	902.64
3	1714.47	364.89	68.37	15.03	851.73
4	1628.98	358.25	62.15	13.66	814.49
5	1547.51	348.71	56.50	12.42	773.75
6	1470.25	337.48	51.37	11.29	735.13
7	1396.79	321.85	46.70	10.26	698.39
8	1326.82	306.85	42.45	9.33	663.11
9	1260.50	292.53	38.59	8.48	630.25
10	1197.33	278.80	35.08	7.71	601.26

Cash in = Revenue

Cash out = Income tax + interest + dividends + property tax

+ maintenance + operating + capital recovery

Table D5.0. Cumulative Cash Flow.

YEAR	CASH IN	CASH OUT
1	1900.02	1564.32
2	3704.88	3061.24
3	5419.35	4483.53
4	7048.33	5837.23
5	8595.84	7129.65
6	10066.09	8356.80
7	11462.88	9517.52
8	12789.70	10615.17
9	14050.20	11654.04
10	15247.53	12639.71

$$NP = 15247.53 - 12639.71$$

$$= 2607.82$$

Where

NP = Present value net cumulative profit

at 10% for a life of 10 years.